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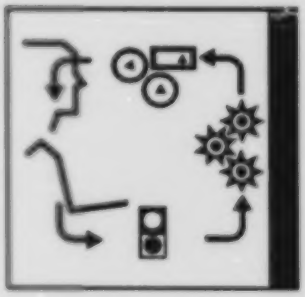
PROCEEDINGS of the SECOND SEMINAR in TRANSPORTATION ERGONOMICS

October 24 – 25, 1990



COMPTE RENDU du DEUXIÈME SÉMINAIRE sur L'ERGONOMIE APPLIQUÉE aux TRANSPORTS

24 – 25 octobre 1990

Canada

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TP 8855

Proceedings of the Second Seminar in TRANSPORTATION ERGONOMICS

Compte rendu du deuxième séminaire sur L'ERGONOMIE APPLIQUÉE aux TRANSPORTS

24 - 25 October / octobre 1990

Transportation Development Centre
Policy and Coordination Group
Transport Canada

Centre de développement des transports
Groupe des politiques et de la coordination
Transports Canada

The contents of these proceedings reflect the views of the speakers and not necessarily the official views of the Transportation Development Centre, Concordia University, or the Human Factors Association of Canada.

The papers are presented in the language in which they were delivered. The opening session and abstracts are presented in both official languages.

Les opinions et les vues exprimées dans ce compte rendu sont celles des conférenciers et ne reflètent pas nécessairement celles du Centre de développement des transports, de l'Université Concordia ou de l'Association canadienne d'ergonomie.

Les articles des communications sont reproduits dans la langue dans laquelle ils ont été remis. La séance d'ouverture et les sommaires sont présentés dans les deux langues officielles.

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16. Abstract

This report contains the papers presented at the Second Seminar in Transportation Ergonomics held at the Guy Favreau Complex Conference Centre, Montreal, 24–25 October 1990. The seminar was co-sponsored by the Transportation Development Centre of Transport Canada, the Department of Mechanical Engineering, Concordia University, and the Human Factors Association of Canada/Association canadienne d'ergonomie. The papers deal with ergonomics applications of vehicle/systems operation and simulator technology in all transportation modes. In some cases, abstracts in both official languages are provided.

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16. Résumé

Ce document renferme les communications présentées lors du deuxième séminaire sur l'ergonomie appliquée aux transports, tenu à Montréal les 24 et 25 octobre 1990, au Centre des conférences du Complexe Guy-Favreau. Ce séminaire a été parrainé conjointement par le Centre de développement des transports de Transports Canada, le Département de génie mécanique de l'Université Concordia et l'Association canadienne d'ergonomie/Human Factors Association of Canada. Les communications traitent des applications de l'ergonomie aux véhicules/systèmes et de la technique de la simulation dans tous les modes de transport. Dans certains cas, les résumés sont donnés dans les deux langues officielles.

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FOREWORD

The seminar reported in this Proceedings follows one presented in October 1987 under the joint sponsorship of the Transportation Development Centre (TDC) and the Human Factors Association of Canada/Association canadienne d'ergonomie (HFAC/ACE). The purpose of the 1987 Seminar in Transportation Ergonomics was to acquaint transportation engineers, designers, and managers with the concepts and approaches of ergonomists, and to bring about a greater understanding of how these two professional groups could work interactively in the field of transportation. So successful was this event that TDC was encouraged to proceed with a series of such seminars, each successive one to focus on a special topic. Accordingly, we are happy to have co-sponsored with Concordia University and HFAC/ACE the 1990 seminar, which devoted itself to problems of vehicle/system operation and simulators.

These events of course are never accomplished without enormous co-operative effort on the part of a small team of dedicated people. Dr Jaro Svoboda of Concordia University, acting as Chair both of the Organizing Committee and of the Engineering Program, contributed very significantly to the conceptual work and ploughed tirelessly through the multitude of planning and organizing details. Julia Rylands of HFAC/ACE was extremely helpful in sorting out numerous administrative entanglements while also performing as Chair of the Human Factors Program; she and HFAC/ACE Secretary Leslie Buck provided valuable input on the content and structuring of the program. Despite her heavy workload at TDC, our Communications Manager, Dina Iwanycky, managed to meet all her deadlines for printed material and still maintain her usual standard of excellence. As Manager of Exhibits and Displays, Marcel Therrien of Transport Canada Public Affairs designed a creative replication of the TDC driving simulator and contributed expertise also in handling all details of the exhibits in the Salle des Pins. Don Beaulieu of Public Affairs gave us a great deal of assistance with public relations. At the base of all this activity, our Administrative Assistant – Christiana Cavazzoni – alternated energetically on telephone, facsimile, and computer to maintain order among the incessant stream of administrative detail. Other members of the Concordia team – Leslie Hosein, Wes Fitch, and Ash Wesseff – worked silently but importantly behind the scenes. To all of these people, we can only offer our warmest praise and sincerest gratitude.

We are grateful, too, to Seminar Chairman Jean Beaubien – who carried out his role with a sense of humour, a bent for amusing anecdote, and immense skill – and to the session chairs, all of whom kept things moving as they should. Panel Chairman Ron Kruk's ability to both provoke and moderate controversial discussion is always appreciated.

Thanks are also due to the speakers whose impressive expertise generated the dynamic content of the seminar.

Finally, warm appreciation must be expressed to the attendees; they were lively in discussion and, without their obvious interest, there could not have been this event.

Ruth M. Heron, Ph.D., M.Erg.S.
TDC Senior Ergonomist
and Seminar Co-ordinator

AVANT-PROPOS

Le séminaire dont il est rendu compte ici fait suite à celui organisé en octobre 1987 par le Centre de développement des transports (CDT) et l'Association canadienne d'ergonomie/Human Factors Association of Canada (ACE/HFAC). Le but du premier séminaire avait été de familiariser les concepteurs, ingénieurs et gestionnaires de systèmes de transport avec les méthodes utilisées en ergonomie, aux fins de rapprocher ces deux disciplines et de permettre à leurs tenants de travailler étroitement ensemble. Le franc succès obtenu alors a été si encourageant que le CDT a décidé d'en faire un événement périodique, autour d'un thème particulier. C'est donc avec joie que nous lançons le séminaire de 1990 avec la collaboration de l'ACE/HFAC ainsi que de l'Université Concordia, le thème principal retenu étant la conduite des véhicules et simulateurs de conduite.

Mais on se rend très bien compte qu'un événement de cette envergure ne se fait pas sans un travail acharné des organisateurs, un comité petit en nombre mais pas en compétence. À commencer par le Dr Jaro Svoboda de l'Université Concordia qui, à la tête tant du comité organisateur que des ateliers techniques, a abattu un travail considérable de réflexion, de planification, et d'organisation. Julia Rylands de l'ACE/HFAC a réussi à démêler l'écheveau administratif tout en organisant avec compétence les ateliers sur les facteurs ergonomiques, dont elle a également défini et structuré le contenu avec l'aide de Leslie Buck. Malgré sa lourde charge de travail au CDT, notre coordonnatrice, Communications, Dina Iwanycky, a respecté l'échéancier dans la production de notre documentation, de qualité toujours impeccable. À titre de coordonnateur, Audio-visuels, notre collègue Marcel Therrien, Affaires publiques, Transports Canada, a réalisé une réplique réussie du simulateur de conduite du CDT et a prêté main-forte dans l'aménagement de la Salle des Pins, lieu de l'exposition audio-visuelle. Les relations publiques ont été menées rondement grâce à Don Beaulieu.

Toutes ces activités n'auraient pu être menées à bien sans le travail inlassable de Christiana Cavazzoni, adjointe administrative, véritable chef d'orchestre entre le téléphone, le télécopieur et l'ordinateur. Il ne faut pas oublier le travail silencieux mais non moins efficace des autres membres de l'équipe Concordia : Leslie Hosein, Wesley Fitch et Ashraf Wassef. À tous, un grand merci du fond du coeur.

Merci aussi à Jean Beaubien, président du séminaire, dont le sens de l'humour et de l'anecdote ne cache pas la compétence, et à tous les présidents d'atelier qui ont su mettre de l'entrain dans les débats. On ne saurait passer sous silence l'habilité de Ron Kruk pour animer les débats controversés entre les congressistes.

Et que dire des conférenciers dont la compétence dans leur domaine respectif a imprimé au séminaire toute la dynamique nécessaire.

Merci enfin aux participants pour leur collaboration animée aux débats, sans laquelle le séminaire n'aurait pas eu le succès que nous lui connaissons.

Ruth Heron, Ph.D., M.Erg.S.
Ergonomiste principale (CDT)
et coordonnatrice du séminaire

SEMINAR BACKGROUND AND OBJECTIVES

Vehicle System Operation and "Human Error"

Always of paramount concern to those in the field of transportation, the question of safety has elicited much creative attention to the engineering of vehicles, ways, and systems. However over the past several years it has become clear that engineering alone cannot bring about further reduction in vehicle accidents – that "human error" figures importantly in the equation. The concept of "error-tolerant-systems" is now being embraced by some safety specialists but, apart from this, most transportation managers are now acknowledging that what is essential in order to minimize mishaps is a greater understanding of the human factors relevant to vehicle or system operation. This is especially true in view of the increasing demands that are being placed on vehicle operators as they interact with both vehicle hardware and network systems, which are following a trend of continually increasing technological complexity. Moreover, proposed plans for automation will undoubtedly give rise to entirely new types of operational errors. It is this kind of thinking that led Transport Canada to place emphasis on human factors with respect to its strategic objectives for 1990 and onward.

Simulators: New Approaches

An indication of the virtually universal determination to increase safety by dealing more effectively with the human factors associated with vehicle/system operation is the mushrooming use of the simulator. The Link Trainer, the rudimentary forerunner of today's sophisticated models, demonstrated during World War II that such a device could (i) reduce costs of both training and R&D, (ii) achieve higher rates of learning and of R&D for both system design and operator performance, and (iii) afford a safer context for the exercise of dangerous or impossible operational tasks. Today, the simulator is increasingly seen by transportation managers as an indispensable tool in these respects. One reason for this trend is that exciting technological advances are opening up the possibility of new approaches to the engineering of simulators, so that users' needs can be met with more cost-effective systems. These developments present challenges to both the engineer and the human-factors specialist, who must work together if system efficiency is to be maximized.

Interdisciplinary Forum

The purpose of this seminar is to provide engineers, ergonomists, training specialists, and transportation managers with a forum for the exchange of up-to-date engineering and human-factors information regarding (i) the problems associated with the operation of vehicles/systems and (ii) the challenging possibilities for R&D and training/assessment solutions to such problems offered through innovative engineering of modern simulator technology. The seminar program features interactive sessions in these areas, each covering the four transportation modes (air/space, road, rail, and marine), as well as final panel discussion. Technical exhibits will also be on display.

In sum, the seminar is designed to foster an interdisciplinary approach to the subject and the greatest possible interaction among speakers and attendees. It will be of interest to managers in operational, safety, regulatory, policy, R&D, and manufacturing areas of transportation, and to ergonomists, engineers, and trainers wishing to know more about the field.

RAPPEL/MISE EN CONTEXTE ET OBJECTIFS DU SÉMINAIRE

L'erreur humaine dans la conduite de véhicules/systèmes

Toujours présent dans l'esprit des responsables, l'aspect sécurité des transports a poussé les ingénieurs et projeteurs de véhicules, d'infrastructures et de systèmes dans la voie d'une créativité toujours plus novatrice. Sauf que, depuis quelques années, force leur est de constater que les perfectionnements techniques ne suffisent plus pour réduire davantage le nombre d'accidents et que désormais la notion d'« erreur humaine » était incontournable. Certains spécialistes de la sécurité misent sur l'idée de « tolérance aux fautes », mais nombreux sont ceux qui ont fini par admettre la nécessité impérative de pénétrer davantage les facteurs ergonomiques entrant dans la conduite des véhicules et des systèmes de transport. Une telle prise de conscience n'a que trop tardé vu les exigences de plus en plus contraignantes placées sur les opérateurs de machines, confrontés comme ils le sont à un matériel, à des systèmes de plus en plus complexes, voire « intelligents ». Et la marche incessante vers une automatisation encore plus poussée fait entrevoir le risque d'erreurs d'un type encore inconnu. Placé devant une telle perspective, Transports Canada entend désormais que, dans les stratégies qu'il cherche à mettre en place pour les décennies à venir, il soit largement tenu compte de tous ces facteurs.

Les simulateurs : tendances et prospective

S'il fallait une preuve de la volonté quasiment universelle d'accroître la sécurité en s'attaquant avec plus d'efficacité aux facteurs ergonomiques entrant dans la conduite des machines, le foisonnement des simulateurs en est une flagrante. Durant les années de la Seconde Guerre mondiale, le simulateur de pilotage appelé Link Trainer, aïeul de nos merveilleuses machines actuelles, a montré qu'avec un tel dispositif, il était possible : i) de réduire le coût de l'apprentissage et de la recherche, ii) d'accélérer l'acquisition de connaissances et l'exécution de la R&D aussi bien en ce qui concerne l'étude des systèmes que la compréhension des facteurs humains en jeu et, iii) de créer un environnement rendant plus sûre l'exécution de tâches difficiles, voire dangereuses. Aujourd'hui, les gestionnaires des transports ont adopté le simulateur sans restriction; entre autres raisons, il y a le fait que, les progrès technologiques aidant, il permet de répondre à toutes les exigences sans cesser pour cela d'être abordable. Mais il ne faut pas perdre de vue que, pour en tirer le plein parti, une étroite collaboration entre ingénieurs et ergonomistes est indispensable.

Interdisciplinarité

Ce séminaire vise à rassembler ingénieurs, ergonomistes, formateurs et gestionnaires des transports en vue d'un échange d'informations touchant : i) les techniques et les facteurs humains reliés à la conduite des véhicules et de leurs systèmes et ii) les possibilités offertes par le simulateur de conception moderne et par ses applications à la recherche et à l'apprentissage. Le programme du séminaire comporte une série d'ateliers interactifs dans tous ces domaines et concernant les quatre grands modes de transports : l'aérospatiale, la route, le rail et la mer, et, pour clôturer le tout, un grand débat général. Des présentations techniques sont également prévues.

Bref, il s'agira d'un séminaire marqué par une approche aussi bien interdisciplinaire qu'interactive, et auquel voudront s'associer tous ceux qui désirent approfondir le sujet si passionnant de l'ergonomie : gestionnaires concernés par les transports sous leurs aspects d'exploitation, sécurité, réglementation, administration, R&D et fabrication, ergonomistes, ingénieurs et formateurs.

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OPENING OF SEMINAR

OUVERTURE DU SÉMINAIRE

The seminar was officially opened by the Chairman, Jean Beaubien, Transportation Analyst, Transport Canada. The opening remarks were delivered by representatives of the sponsors:

- Micha Avni, Chief, Advanced Technology Division, Transportation Development Centre, Transport Canada;
- M.N.S. Swami, Dean of Engineering and Computer Science, Concordia University; and
- David Beattie, President, HFAC/ACE.

The keynote addresses followed these remarks.

Le Deuxième séminaire a été officiellement ouvert par le président, Jean Baubien, analyste en transport, Transports Canada. Les discours d'ouverture ont été faits par les représentants des organismes parrains :

- Micha Avni, chef, Technologie avancée, Centre de développement des transports, Transports Canada;
- M.N.S. Swami, doyen, Sciences informatiques et ingénierie, Université Concordia; et
- David Beattie, Président, ACE/HFAC.

Les discours-programme ont été donnés après ces discours d'ouverture.

KEYNOTE ADDRESS

Integration: The Ergonomist's Approach to System Design

Patti Rothwell
Defence and Civil Institute of Environmental Medicine
North York, Ontario

Many professions now express their recognition of the importance of human factors/ergonomics. People who are involved in vehicle and simulator systems are not the least of these. They, particularly, recognize the valuable input ergonomists bring to implementing these systems. I would like to discuss a concept of where ergonomists fit in this community, by talking about the word "integration."

I see integration as being the essence of the approach that ergonomists must take in designing and solving problems of systems. It is an approach that insists that the big picture – the reason for a system's existence – always be kept in view, while bringing together diverse elements that comprise the whole. Hence, it insists that ergonomists go beyond the scope of their individual areas of expertise in understanding system interactions. In developing this idea I do not suggest that other professions do not integrate diverse information. But I believe there is a unique contribution that ergonomists offer. Here, I make a broad assumption. I assume that almost all systems are designed to provide a service, protect, or in some other way assist the human being. And this is the assumption I believe ergonomists should bring to system design or system problem solving.

Integration provides a way of looking at design and evaluation to ensure that the human remains at the centre of concern. One may ask how this view of integration is obtained. Perhaps it starts in the way ergonomists are taught and trained, or perhaps it is acquired more through our apprenticeship. Certainly, it is re-affirmed throughout our work experience as practitioners – that we, as individuals coming from specific educational backgrounds such as physiology, psychology, engineering or biomechanics, must step outside the teachings of our parent disciplines and look at the world through the eyes of those from other disciplines. We must appreciate, respect and accept a wide diversity of viewpoints.

But first, what is ergonomics? Ergonomics is about people. It is concerned with relationships of people with all aspects of their lives – in their working and living environments, and with other people. Its focus is to balance human comfort and safety with overall system efficiency. And this is done by making sure that wherever the human is involved there has been due consideration of his needs, and his influence on the system's performance.

We accomplish this with knowledge of human capabilities and limitations. Drawing heavily upon the human sciences, we look at the strengths of the human being (which may include, for example, proprioceptive feedback, touch, the ability to synthesize a large amount of visual information at one time, etc.). We also look at the weaknesses of the human (which, in a given situation, may include physical strength, the ability to retain information, memory, etc.). In contributing to design or evaluation, we take a systems approach, looking at the human as a sub-component of a bigger system. We look at how the functions are (or should be) allocated between the human sub-component and the other sub-components of the system. Then, we offer solutions to needs for interactions that involve or affect the human sub-component.

The system itself can be defined at very different levels. Consider the training simulator. We may look at that system as having a human trainee at the centre of a complex network of technological elements that are designed using contributions of people ranging from hydraulics specialists, mechanical engineers or electrical engineers, to people who are knowledgeable about the presentation of visual displays, and so on. Or we may view the system as more encompassing. We may include simulator operation and maintenance personnel. The person conducting the training session may work some distance away from the simulator itself and have a quite different working environment, while interacting with the trainee in the simulator. When the training session is over, maintenance staff may have to manoeuvre in and around the simulator to make changes, or to evaluate the performance of simulator sub-components. Or, we may look at the system as being still larger than

that. Consider the system that includes simulator scheduling. It may represent a host of different concerns, such as the demands for availability of the simulator to people who must be trained, who run the training sessions and who maintain the simulator. Overlapping these issues may be the need to provide adequate rest allowances for trainees to avoid carry-over effects between training in the simulator and operating in the "real world." So, the system can be considered at very different levels. And we can see that there are many ways in which human beings may interact with the system.

Engineers cannot and should not be expected to understand the complexities of human interactions within the system. Yet they do recognize that human beings contribute to systems' successes and failures. Schematic drawings of systems often bear this out. Flow diagrams frequently incorporate the human component in detailed illustrations of human/process/environment interactions. Unfortunately, the human component is simply labelled "human," or "operator," or "user." Essentially, the human is treated as a black box.

This is where I believe ergonomists play a central role. We can take some of the mystery out of that black box. Our educational backgrounds, offering understanding of various aspects of human capability and limitation, facilitate that role. Complementary to our knowledge, we exercise understanding of the multi-disciplinary factors influencing human performance. This allows us to recognize when our expertise may not be sufficient, and to seek out specialists who do have relevant knowledge and expertise.

The importance of taking full consideration of the human sub-component is that design trade-offs almost always have to be made that affect the human. Members of the design team cannot expect to fully satisfy all the needs of the human, just as they cannot expect to satisfy all the needs and desires of different engineering components. It may be a straightforward task to express what is needed from the standpoint of individual design issues (such as visual stimuli, or combinations of visual and motion stimuli, or ideal training times and scenarios, to name a few). But these often represent ideal conditions that cannot always be provided. For example, trade-offs may suggest that visual displays cannot be as precise, or that sensory feedback cannot be as exacting as desired, or that all potential environments that may be encountered in real life simply cannot be presented. At this point, time, money and all the other design constraints come into play. And some of the requirements of the human black box have to be passed over. The criticality of ergonomics input comes into play when these trade-offs are made.

Optimization is the key to determining trade-offs. In the case of the simulator system, ergonomists not only must identify the humans' needs, but they must also ensure that the most important of those needs are met. As expressed earlier, they must participate in identifying trade-offs between human needs and other considerations such as the level of fidelity that time and cost permit. On the other hand, they must safeguard against excessive uses of technology that go beyond human performance capabilities or overall system requirements. So, measures of human and system performance are also important – the measures must assess satisfaction of the design goals that were laid out to satisfy the human needs in the first place.

These issues cannot be taken lightly. System fidelity, and the disparity in experiences within simulated and real environments can be of critical importance. Why? Partly because of the potential mismatch users may encounter between expectations they formulate in the simulated environment and subsequent experiences they may have in real operational settings. There are many simple examples of the importance of design optimisation. One example can be drawn from a design issue that was raised during a home driver-education program conducted across Canada a few years ago. A number of civilians from across the country were put through a driver training program which was broadcast on national television. Viewers were given pointers on how they should and should not operate a motor vehicle. One particular demonstration was on four-wheel lock braking. During the demonstration, it came to light that one participant simply could not achieve the desired braking effect. This was in spite of numerous attempts, and individualized training. The driver trainers eventually determined that the participant was physically unable to complete the task. With the car seat moved full forward, she did not have sufficient leg reach to fully depress the brake pedal. Consequently, she could not get all four wheels to lock.

The car used for the demonstration was of standard North American design. Presumably, it had been designed to suit the North American population (usually stated as being designed for the 5th to 95th percentile driver, suggesting that the car is satisfactory for at least 90% of the driver population). Evidently, the participant in question either did not fall within the bounds of the design population, or the car did not accommodate the population for which it was designed. I think the most significant factor is that she

had been driving for years and had no idea that she was not able to apply the brakes fully. An important lesson to be learned from this is that she did not have adequate understanding of how the system should perform to be able to judge her own performance in the system.

Situations such as this come about because designers combine system components (such as vehicle mechanicals, instruments, mirrors and seats) without adequate consideration of their interactions. And when human variability is introduced to the system, satisfaction of one performance requirement may be met at the expense of another. This highlights the need for integration, where ergonomics can be applied to investigate interactions (e.g., adjustment parameters and combinations for seat, pedal, and mirror positions) so as to satisfy the requirements of a wide variety of individuals. Such scenarios also illustrate that we must not only understand the strengths and shortcomings of systems, but we must convey them to the appropriate people, and in an appropriate manner.

I see the process of integration, then, as a method of optimisation which is achieved in two ways. One way is through application. The other way is through communication. By application, I mean going beyond theoretical bounds to make practical decisions. To do this, I believe ergonomists must approach problems as generalists, taking a broad view of how different factors combine to ensure that the human is considered fully in the system. Whenever possible, ergonomists should use a scientific approach in looking at human/machine/environment interactions. This includes using published literature and scientific methods of measurement and analysis as bases for decision making. However, practical skills also come into play. Where people are involved, one or more user trials may be necessary at some time in the design cycle. As ergonomists, we must go beyond laboratory experience and try systems out in the real world. Hence, field experimentation is also important. This requires task analyses, and ways of getting information from users who don't speak the language of specialists or design team members.

But systems vary a great deal, and constraints on the design cycle sometimes prohibit independent investigation. On those occasions, certain aspects of human interactions within a system may remain unidentified. In those instances, extrapolations have to be made without the benefit of experimentation or prior understanding of human responses to the dynamics of the system. This leap, from using scientific evidence and field experiments as the basis for decision making, to making extrapolations and generalizations about human beings is where, in my view, the talents of good ergonomists lie. As ergonomists, we must be prepared to take what we know, what we've seen and what we can glean from specialists in human capability and limitation, and be prepared to suggest what ramifications may result from making given trade-offs.

Communication is the other aspect of integration I wish to discuss. By communication, I refer to the way that the ergonomist facilitates the design process while acting as a watchdog to ensure that the human remains at the centre of concern in the system. This is critical because no matter how good our work is, if we cannot communicate our message, it is useless.

Communication happens at several levels. We obtain information from specialists, we integrate the input of specialists, and we express our views within and on behalf of the design team.

Given that individual ergonomists do not know all aspects of human function and performance, specialists must often be consulted. Therefore, we seek to recognize when specialists are needed and to know where to find them. In speaking to those specialists, ergonomists must pose the questions in ways that are germane to the problems so that the most relevant information is obtained. We must then be able to look at the feedback in ways that address the design (or evaluation) objectives. And the feedback must be coordinated with system criteria and constraints that influence the overall system. The talent lies in the way the questions are phrased to the specialists so that the answers can be interpreted to achieve design solutions.

Most ergonomists also impart information that represents their personal expertise. Here again, communication must be very straightforward. Ergonomists must not insist that other designers deduce for themselves the information presented. We should deliver a practical bottom line – in a way the designers can understand.

There are often other interest groups that must also appreciate design considerations and decisions. Because of this there are ergonomists who specialize in taking information from a design team and imparting it to management, to workers, and perhaps to the public at large. This role is essential to ensure that there is little or no resistance to change, and that the opportunity for the system's success is facilitated as far as possible. How? By committing people to the value and merits of the design.

So integrated communication is not just how the design questions are phrased. It is also how the design answers (or solutions) are delivered.

In design and evaluation, there is real potential for risk when generalizations must be made about human performance and behaviour. This is because people vary and people change – they come from different backgrounds of experience and education, they age, they deteriorate in memory and reaction time, and so on. Technology changes; it becomes more advanced. And we make broad assumptions about people's understanding and mental maps of technology, and how they may change along with the technology. Environments also vary. If we consider the vehicle simulator environment many events can be modelled. But we probably cannot simulate the eye of a hurricane. We certainly cannot simulate personal states of the operator (such as emotional stresses, fatigue, or fear of consequences). There are many elements that can degrade human performance within a system, and we cannot account for all permutations.

I will argue that ergonomists should accept the challenges of this risk. In the face of uncertainty, we should still work at integrating the human in the system and make our best estimate (sometimes through the input of other specialists) as to how the human can best be accommodated by the system. But acceptance of this risk requires some cooperation.

First, to be given a fair chance, ergonomists must be brought into design work before the concepts are laid down. Otherwise, our hands may be tied, from the start, by decisions that already have been taken. Second, we must be fully briefed, and maintain full briefing on design constraints on the overall system – including issues that go beyond what others may believe to affect human aspects of the system. This is because the effects of those constraints will have to be studied with respect to their influence on human performance and well-being. Third, others working on the design team must be tolerant, and understand this risk. There are almost always areas of uncertainty that ergonomists must cope with in applying our knowledge and skill. Experiments should be done, when possible, and there should be tolerance for that. But rules and principles for making decisions will not always exist, and that must also be accepted.

It is my impression that people presenting papers at this symposium include specialists, generalists, practitioners, and researchers. I suggest those who profess to represent human factors issues should accomplish several things. Their talks should convey the relevance of the human component to overall system performance. It should be self-evident that the human takes priority in all considerations for the system's design. And, their messages should be delivered in a manner that you, the audience, can understand without ambiguity.

DISCOURS-PROGRAMME

L'intégration : une démarche ergonomique dans la conception d'un système

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Parmi les nombreux professionnels qui admettent désormais l'importance de l'ergonomie, les concepteurs de véhicules et de simulateurs ne sont pas les moindres. Ces derniers, en effet, reconnaissent maintenant l'apport de l'ergonomie dans la réalisation de ces systèmes. Là-dessus, je voudrais traiter d'un concept susceptible d'éclairer le rôle des ergonomistes dans le contexte de l'ingénieur, et qui est celui de l'intégration.

À mon avis, l'intégration est à l'origine de toute démarche entreprise par les ergonomistes dans le leur choix de solutions à tel ou tel problème. L'intégration est un concept qui veut que l'ergonomiste ne perde jamais de vue la totalité du problème à résoudre, lorsqu'il tente de mettre ensemble les diverses parties constitutives d'un système. Ce concept exige que l'ergonomiste, tâchant de comprendre les interactions en jeu, déborde le champ de sa stricte compétence. Attention, je ne veux pas dire par là que les divers ordres d'ingénieurs ne s'occupent pas d'intégration. Ce que je veux dire c'est que l'approche de l'ergonomiste est unique. En faisant cette affirmation, je suis obligée de faire une hypothèse : lorsqu'on parle de systèmes, il s'agit presque toujours de systèmes conçus pour aider d'une manière ou d'une autre l'être humain à réaliser quelque chose. C'est d'ailleurs l'hypothèse que les ergonomistes doivent retenir à mon avis lorsqu'ils s'attaquent à la conception d'un système ou à la recherche de solutions à un problème.

L'intégration, donc, assure que dans tout processus de conception ou d'analyse, l'aspect humain demeure au centre des choses. On pourrait se demander comment s'acquiert cette vue de l'esprit. Je répondrai en disant que c'est peut-être une question d'apprentissage, ou peut-être de formation. Mais, ce qui est sûr, c'est que cette notion s'affirme tout au long de l'expérience que nous, ergonomistes, physiologues, psychologues, biomécaniciens ou autre, appliquons tous les jours, et qui nous amène à appréhender le monde avec les yeux des praticiens de disciplines qui ne sont pas forcément les nôtres. Autant de points de vue que nous admettons, respectons et envisageons.

Mais, tout d'abord, qu'est-ce que l'ergonomie ? L'ergonomie est une discipline qui s'intéresse au fonctionnement de l'être humain en activité, et aux relations que ce dernier entretient avec son environnement de travail, de vie et avec autrui. Elle cherche à harmoniser le confort et la sécurité de l'être humain avec l'efficacité du système qu'il doit faire fonctionner. Pour cela un seul moyen : s'assurer que toujours et partout on ait tenu compte de ses spécificités et de son influence sur le rendement global.

Nous tâchons avant tout de bien cerner les côtés forts et les côtés faibles de l'être humain. Élargissant nos connaissances des sciences humaines, nous établissons le bilan des possibilités de l'être humain : réaction proprioceptive, toucher, aptitude de synthèse d'informations visuelles, etc. Et aussi de ses limites : force, résistance, faculté de mémorisation, etc. Lorsque nous abordons un problème de conception ou d'analyse, nous considérons l'être humain comme un des sous-systèmes concourant au fonctionnement du système global. Nous voyons comment les fonctions sont ou devraient être partagées entre ces divers sous-systèmes. Et c'est alors que nous dégageons des solutions aux interactions en jeu, dans la mesure où elles intéressent, touchent ou impliquent l'élément humain.

Un système peut se définir à divers niveaux. Prenons le cas du simulateur destiné à l'apprentissage. Il est possible de le définir comme étant constitué d'un être humain en formation placé au centre d'un réseau complexe d'éléments dont la réalisation fait appel à des technologies très diverses : hydraulique, mécanique, électricité, présentation visuelle d'informations, etc. Il est possible aussi d'élargir cette définition en tenant compte d'autres aspects tels que l'exploitation du simulateur,

son entretien, etc. Sous cet angle, il faut penser que l'agent de formation peut se trouver être loin du simulateur, dans un environnement tout à fait différent de celui du simulateur dont il a à régler le fonctionnement. Lorsque la séance est terminée, le personnel d'entretien doit pouvoir évoluer à l'intérieur et à l'extérieur du simulateur dans l'exercice de ses fonctions : modifications, analyse des performances des parties constitutives du simulateur, etc. Il est possible aussi de définir le système à un niveau encore plus élargi : par exemple, celui de l'ordonnancement des séances de formation. La gamme des contraintes peut être très vaste : conflits dans les demandes de mise à disposition, caractéristiques des opérateurs : stagiaires, agents de formation, personnel d'entretien. Et il ne faut pas oublier les autres contraintes comme celle de prévoir des périodes d'assimilation pour éviter aux stagiaires les traumatismes dus à l'absence de transition entre le monde de la simulation et celui de l'exploitation réelle. Il existe donc autant de définitions qu'il y a de degrés dans les interactions homme-machine.

Un ingénieur ne peut pas appréhender les interactions homme-machine dans toute leur complexité, et là n'est pas son rôle. Mais on s'aperçoit qu'il se rend très bien compte de leur influence sur le succès ou l'échec du système à l'étude. À preuve, les schémas de principe dans lesquels on constate souvent la présence de l'élément humain dans l'illustration de l'organisation homme/procédé/environnement. Malheureusement, cet élément humain ne figure simplement que sous le libellé de : « élément humain » ou « opérateur » ou « utilisateur ». En d'autres termes, ce n'est rien de plus qu'une autre « boîte noire ».

C'est ici que, à mon avis, les ergonomistes ont un rôle fondamental à jouer : expliciter le contenu de cette « boîte noire », que leur formation et leur compréhension des côtés forts et faibles de l'être humain les préparent à entreprendre. S'appuyant sur des connaissances étendues, ils peuvent approfondir les facteurs multidisciplinaires conditionnant les performances humaines. Mais lorsqu'ils se rendent compte qu'elles ne suffisent pas, c'est alors qu'ils font appel aux spécialistes des disciplines qui leur manquent.

L'importance attachée à la prise en compte totale de l'élément humain dans tout système s'explique par le fait que des compromis doivent inévitablement se faire et qu'ils ne sont jamais sans effet sur cet élément humain. Pas plus qu'il ne peut répondre à toutes les exigences techniques d'un système, le bureau d'études ne peut satisfaire tous les besoins de l'être humain. S'il est relativement simple de satisfaire les exigences reliées à une fonction donnée (stimulation visuelle seule ou combinée à la cinématique ou ordonnancement des séances et des scénarios de formation, par exemple), il est beaucoup plus difficile de les réaliser, car il s'agit souvent de situations idéales qu'on ne peut pas toujours offrir. Par exemple, il se peut qu'un compromis nécessaire aboutisse à un affichage d'une précision moins grande ou à effet sensoriel moins frappant que voulu, ou à un environnement simulé moins fidèle que la réalité. À quoi pourraient aussi s'ajouter d'autres contraintes, de temps, d'argent ou de technologie, avec le résultat que certaines des exigences humaines définies doivent être abandonnées. C'est à ce moment, au moment où des compromis s'imposent, que l'ergonomie prend toute son importance.

Seule l'optimisation permettra de trancher entre les compromis à effectuer. Dans le cas du simulateur, les ergonomistes doivent non seulement définir les exigences rattachées à l'élément humain, mais aussi garantir qu'elles seront satisfaites, les plus essentielles d'entre elles, du moins. Comme il a été dit tantôt, ils doivent participer au choix des compromis à faire entre besoins humains et toutes les autres considérations non humaines, comme le degré de réalisme et les contraintes de temps et d'argent. D'un autre côté, ils doivent veiller à ce que les performances exigées ne dépassent pas ce que l'être humain et même le système dans son ensemble est en mesure de fournir. Conclusion, les performances tant humaines que systémiques doivent pouvoir être mesurées, dans le but de déterminer jusqu'à quel point le système envisagé est en mesure de satisfaire les exigences qui avaient présidé à sa définition première.

Ce sont toutes des questions que l'on ne peut prendre à la légère. En effet, le réalisme du rendu ainsi que la divergence entre expérience théorique et expérience pratique peuvent constituer des éléments de haute criticité. Pourquoi ? En raison des divergences possibles entre résultats obtenus en milieu d'exploitation simulée et d'exploitation réelle. Pour illustrer l'importance de l'optimisation systémique, les exemples faciles à décrire sont nombreux. En voici un tiré d'une discussion autour d'un programme de formation en conduite automobile à domicile diffusé au Canada il y a quelques années. Une émission télévisée avait été tirée de ce programme alors administré à un certain nombre de personnes. Les téléspectateurs écoutaient les commentaires qui soulignaient ce qu'il fallait et ne fallait pas faire en conduite automobile. Le programme portait entre autres sur le freinage par

blocage des quatre roues du véhicule. Or il est apparu qu'une des personnes participantes ne parvenait pas à produire un freinage total, malgré les nombreux essais répétés et les conseils prodigués. Il a été finalement constaté que cette personne était physiquement incapable d'accomplir cette tâche et que, même avec le siège en position avancée, sa jambe ne réussissait pas à appuyer à fond sur la pédale du frein. Et c'est pourquoi le freinage n'était pas total.

Or le véhicule utilisé était d'un modèle nord-américain standard. Il faut croire qu'il avait été conçu en fonction de la population nord-américaine, c'est-à-dire pouvant convenir à des conducteurs appartenant au groupe statistique délimité par les 5e et 95e centiles, soit au total 90 p. 100 de la population. De deux choses l'une, soit que la personne en question se situait en dehors de ce groupe, soit que le véhicule ne rejoignait pas la totalité du groupe auxquel il était destiné. Mais ce qu'il faut retenir, c'est que cette personne conduisait depuis de nombreuses années et que jamais elle ne s'était rendue compte de son incapacité d'effectuer un blocage total des freins. Conclusion, cette personne qui ne savait pas suffisamment bien comment le système était supposé fonctionner, n'était donc pas en mesure d'évaluer ses propres performances.

Si de telles situations existent, c'est parce que les concepteurs assemblent des sous-systèmes (organes mécaniques, accessoires, sièges, etc.) sans vérifier leur compatibilité. Et lorsque l'élément humain est introduit dans la boucle, il n'est possible de satisfaire à une exigence fonctionnelle qu'au détriment d'une autre. D'où l'importance de l'intégration, et de l'ergonomie chargée, elle, de vérifier les compatibilités, c'est-à-dire les réglages des organes et des accessoires les uns par rapport aux autres, de manière à convenir à un maximum de personnes. Il ressort de tout cela que les ergonomistes doivent non seulement approfondir les côtés forts et faibles de chaque système, mais aussi le faire savoir à qui de droit, de la manière appropriée.

Pour moi, l'intégration atteint à l'optimisation par les deux moyens que sont le pragmatisme et la communication. Par pragmatisme, j'entends l'obligation de déborder la théorie pour arriver à des décisions pratiques. Pour cela, les ergonomistes doivent aborder tout problème dans son ensemble et envisager comme le ferait un praticien généraliste tous les facteurs en jeu et leur effet sur l'élément humain une fois introduit dans la boucle. Ils doivent, dans la mesure du possible, adopter une approche scientifique face à toute organisation homme/machine/environnement, c'est-à-dire prendre des décisions fondées sur des documents connus, des mesures prises scientifiquement et des analyses, et s'appuyer sur des expériences vécues. C'est ainsi que, à l'égard de tout système comportant un ou des éléments humains, des essais pratiques doivent être introduits dans le cycle de conception. Les expériences de laboratoire ne doivent pas suffire, elles doivent être confrontées à la réalité. D'où la nécessité des expérimentations sur le terrain prévoyant une analyse des tâches puis l'aptitude de traduire en termes scientifiques les informations recueillies auprès des opérateurs.

Mais, devant la diversité des systèmes, et à cause de contraintes introduites dans le cycle de conception, il arrive parfois qu'une étude indépendante ne puisse se faire et que cela empêche la mise en évidence de certaines interactions homme-machine et oblige à des extrapolations non vérifiées par des expérimentations ou ne s'appuyant pas sur des connaissances ergonomiques précises. C'est à mon avis dans ces occasions, c'est-à-dire lorsqu'il faut sauter du domaine des preuves scientifiques et des expérimentations à celui des extrapolations et des généralisations sur les spécificités de l'être humain, que les vraies compétences de l'ergonomiste peuvent être le mieux mises à profit. L'ergonomiste est donc la personne qui, à partir de ce qu'elle sait, a constaté et a appris des spécialistes de la pyschologie et de la biomécanique, est en mesure de décrire les conséquences possibles d'une décision entraînant un compromis.

L'autre moyen de l'optimisation est la communication, c'est-à-dire l'aptitude à intervenir dans le cycle de conception en ramenant sans cesse les considérations sur les spécificités de l'être humain. Or sans l'aptitude à communiquer ce message avec conviction, celui-ci risque de ne pas être entendu.

Le processus de communication se fait à divers niveaux. Appel aux spécialistes, intégration des données reçues et comptes rendus destinés à faciliter la recherche ou à en faire la synthèse.

Étant donné qu'un ergonomiste ne saurait tout savoir sur les fonctionnalités et les aptitudes de l'être humain, il faut faire appel à des spécialistes, donc savoir quand cela devient nécessaire et où les trouver. Il faut savoir aussi poser les bonnes questions de manière à obtenir les données appropriées. Celles-ci doivent alors être analysées de manière à les approprier aux objectifs fixés à la recherche et à les adapter aux critères et contraintes conditionnant celle-ci. Tout l'art de l'ergonomiste consistera donc dans la manière d'exprimer les desiderata et d'interpréter les informations reçues de manière à en tirer des éléments de réponse.

L'ergonomiste doit aussi savoir transmettre son appréciation du problème. Là encore, l'aptitude à communiquer est primordiale. Mais, attention, le message doit être explicite, sans ambiguïté possible quant au contenu.

Mais l'intérêt de l'ergonomie ne se limite pas à ce que je viens de dire. Il y a plus, exemple les ergonomistes qui se spécialisent dans la vulgarisation, c'est-à-dire l'aptitude à expliquer à tel ou tel groupe d'auditeurs ou de lecteurs non spécialistes les finalités du système et ses fonctionnalités. Dans le but de prévenir ou d'atténuer la résistance au changement ou d'optimiser l'accueil qui peut lui être fait. Comment ? En se faisant l'interprète de l'utilité ou de l'intérêt du concept proposé.

Bref, par communication je n'entends pas seulement l'aptitude à poser les bonnes questions, mais aussi à transmettre les bonnes réponses.

Toute généralisation sur le comportement et les performances de l'être humain peut être dangereuse lorsque sa finalité est la conception ou l'évaluation. Les raisons en sont multiples : chaque être humain est unique, il diffère de par son éducation et son expérience. Il vieillit, ses facultés faiblissent, ses réflexes ralentissent. D'un autre côté, la technologie progresse sans arrêt, et nous sommes amenés à des généralisations sur l'attitude de chacun vis-à-vis les changements technologiques et sur l'évolution de sa pensée à cet égard. Les environnements aussi ne sont jamais les mêmes. Les possibilités d'un simulateur, par exemple, sont très nombreuses certes, mais il ne saurait reproduire ce qui se passe dans l'oeil d'un cyclone. Et nous ne savons pas reproduire non plus les états d'âme d'un opérateur : émotion, fatigue ou appréhension, autant de facteurs perturbateurs dont l'évolution et les combinaisons multiples sont impossibles à pronostiquer.

À mon avis, ce sont les risques du métier de l'ergonomiste, qui ne doivent pas empêcher celui-ci de tenter par tous les moyens à sa disposition (notamment l'apport d'autres spécialistes) de réussir l'intégration de l'être humain dans un système. Mais pour réussir dans un tel contexte, il lui faut pouvoir compter sur un minimum de coopération.

Il faut tout d'abord que l'ergonomiste soit invité à intervenir tôt dans le processus de création, justement pour éviter qu'il ne soit handicapé par des décisions prises sans sa participation. Ensuite, il doit être tenu au courant de ce qui se fait et des contraintes qui pèsent sur les décisions à prendre, même dans des domaines que certains prétendraient ne plus relever de l'ergonomie. Cela, afin de pouvoir déterminer l'effet des diverses contraintes sur le comportement et le bien-être de l'élément humain dans la boucle. Enfin, il faut que les autres membres de l'équipe acceptent de composer avec ce risque. Et comme les incertitudes sont nombreuses dès lors qu'il s'agit de passer de la théorie à la pratique, il faut accepter de passer par l'étape des expérimentations, même s'il faut du temps pour les mener à bien. Quant aux décisions, elles ne sont pas toujours régies par des règles ou des principes. Et cela aussi, il ne faut pas l'oublier!

En terminant, à moins de me tromper, aussi bien des spécialistes, des généralistes que des praticiens et des chercheurs présenteront des communications à ce séminaire. Si je puis me permettre un souhait, c'est que leur message fasse ressortir l'importance de l'élément humain dans l'organisation homme-machine et souligner sa prépondérance sur l'élément non humain, le tout dans un discours direct et sans ambages.

KEYNOTE ADDRESS

Vehicle Operation and Simulators: The Engineer's View

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Transportation – the business of moving people and/or goods from A to B safely, economically, and expediently – has represented an ancient engineering challenge. Without transportation, the exchange of ideas and technology would be so limited that the progress of human society would be impossible.

For even the simplest transportation system to work, we need functioning machines and equipment – vehicles are the mobile subsystems, while ports, roads, signage, and so on comprise the stationary subsystems. Equally important, though, we need people to operate the vehicles as well as parts of some of the stationary subsystems. In the "good old days", there were only simple man/machine systems such as horse-drawn cars and sailing ships. Because they moved very slowly through low-density traffic environments, they required relatively simple operational skill. However the problem with this "good-old-days" type of transportation is that it was neither safe nor economical, and certainly not expedient.

With the advent in the early 19th century of portable sources of mechanical power such as the steam engine and, later, the internal combustion engine, transportation technology (like other technologies of the industrial revolution) began developing very rapidly. By the mid 19th century, we were in fact carried into a sort of golden era of t... eportation that lasted to the middle of the 20th century. It was also a rather innocent era of engineering, since it was assumed that all problems were solvable with better and/or more technology and perhaps a bit more operator training.

And it actually worked for a while. Ships and trains became faster and safer, the automobile was born and quickly became a practical vehicle, and so did the youngest and most progressive transport machine, the aircraft. Distance and speed records were broken again and again and, indeed, there seemed to be nothing to stop our march towards a paradise built on technology. But warning incidents began to occur – the most famous one, perhaps, being the sinking of the "unsinkable" *Titanic* as a result of crew error – these suggesting that engineering and technology might not be able to provide all the answers in the development of safe transportation systems.

Although looking back nostalgically at the "good old days" we may regard ourselves today as being in the "bad current days", we are actually rather close to achieving safe, economical, and expedient transportation. But we got to this point only by realizing that transport machines and their operators' skills are very complex and that, for this reason, technology cannot tell us all we need to know to design efficient transportation systems. We recognized, first, that it is necessary to view the human operator as an integral part of the system, and that human limitations of sensation, perception, cognition, and motor performance must be considered under all types of conditions, especially those that induce stress, boredom, and fatigue. We saw, too, that innovative methods of design and construction are needed if the machine is to accommodate the "man-in-the-loop" and that, correspondingly, innovative methods in the selection, training, and assessment of operators are needed if operator skills are to be adapted to the machine. In other words, we engineers came to understand that we had better co-operate with these strange characters, the ergonomists and human factors specialists. A turn-about approach that can almost be called an achievement, considering the basically conservative nature of the engineering community!

When we consider simulator technology, we find a very good fit to the philosophy mentioned above of moving, on the basis of the idea of integrated man/machine systems, toward novel methods of training and assessing operators and of designing equipment. It all started with the outbreak of WWII when demand soared for pilots, the operators of the then most complex vehicle, the airplane. The famous Link trainer, however primitive by today's standards, enhanced considerably the training of thousands

of Allied pilots. The idea caught on, and simulator technology began improving rapidly. Digital computers replaced analog computing circuits, initially just for the flight dynamics model calculations, later on for such demanding tasks as generating the visual scenes and creating force-feel cues for controls. This trend greatly improved simulator systems' reliability, fidelity, and design flexibility.

Technology became so good, in fact, that given enough money, we engineers can now design and build a simulator environment practically indistinguishable from the real thing: indeed, today's simulators are so sophisticated that an airline pilot, after training solely in such a machine, can step into an airliner full of passengers and confidently and safely fly it away. And if, for example, a new airliner is being developed, we can rely on data from a simulated version to test the design of the real airplane. Furthermore, in accident investigation, we can use high-fidelity simulators to reconstruct the situation that existed before a crash. All of this is certainly very impressive. And surely it appears that, this time, we engineers have it nailed down – pure engineering supporting other pure engineering. Almost right! But not quite!

Some nagging problems suggest that a quantitative solution – i.e. throwing on more technology and money – is not going to be enough. What we need is a qualitative breakthrough, and this can be achieved only by co-operation with our ergonomist colleagues. Let me mention a few problems for which their input is essential:

- The existing simulator supertechnology is very expensive. This may be fine for aviation where there is really no alternative to use of simulators. But what about other transportation modes for which simulator technology would certainly be beneficial but is not affordable? Less costly designs seem to provide an answer. But if this approach is to be adopted, where can we take short cuts? Or, in other words, how much fidelity or sophistication is enough?

- Certain make-believe cues or situations cannot be achieved even with the supertechnology – e.g. simulation of a sustained high "g" environment or of stress-inducing emergency situations. Could perhaps new ways to "cheat" believably be found?

- Another problem relates to measurement of operator performance. Existing techniques, based on overt behavioural measures, are all somewhat imprecise. Could new, more incisive concepts, for example those based on brain behaviour measures, be exploited?

- Certainly, current training and research applications of simulator technology are many and quite varied. And new applications such as part-task training are emerging. But how about working towards other novel uses of the simulator, e.g. as an operator selection tool, or as a means of individualizing training?

So here we are with a lot of questions to be addressed. Obviously, engineers will not be able to find satisfactory answers on their own, and so there is real opportunity for us to work together with ergonomists and human factors specialists in using new technology and approaches in the development and application of this fascinating and useful device, the simulator.

And this is what the seminar is all about. It was not created in a vacuum, but rather on reflection of current trends and needs in the areas of vehicle/system operation and simulators. We hope to stimulate discussion about these topics among all interested professionals, and to inform them of some of the solutions the young simulator technology may offer to operation and training problems. Let's do our best to ensure that our meeting fulfills this aim.

DISCOURS-PROGRAMME

Aspects techniques des véhicules et des simulateurs

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Le transport efficace, sûr et économique de personnes ou de marchandises entre deux points géographiques a depuis toujours constitué un défi technique. En effet, sans transports, l'échange d'idées et de technologie se tarirait au point de rendre impossible toute émulation entre les humains.

Tout système de transport, aussi primitif soit-il, repose sur deux sous-systèmes opérationnels : un mobile – les véhicules – et un fixe – l'infrastructure. Mais il faut aussi des opérateurs pour faire fonctionner les véhicules et pour exploiter telle ou telle partie de l'infrastructure. Durant ce qu'il est maintenant convenu d'appeler la « Belle époque », les systèmes homme-machine étaient simples. Pensons aux voitures hippomobiles et aux bateaux à voile. Parce qu'ils se déplaçaient très lentement et que le trafic était faible, il ne fallait pas beaucoup d'habileté pour les faire fonctionner. En revanche, ces systèmes n'étaient ni sûrs, ni économiques et surtout pas efficaces.

Lorsque, au début du XIX^e^ siècle, apparurent les premières machines motrices, d'abord à vapeur et plus tard à combustion interne, la technologie des transports, comme d'ailleurs toutes celles créées par la révolution industrielle, se développa rapidement. Vers le milieu de ce siècle commença alors une espèce d'âge d'or des transports qui dura tout un siècle, marqué au coin d'une naïveté technologique qui portait à croire que tout problème pouvait être résolu par la technologie et par une meilleure formation de l'opérateur.

Le plus drôle, c'est que tout fonctionna comme prévu. Bateaux et trains allèrent de plus en plus vite et la sécurité progressa. L'automobile devint très vite une nécessité, tout comme le sera plus tard l'avion, le fin du fin de tous les modes de transport. Il n'y avait pas de records de distance ou de vitesse qui ne fussent battus aussitôt marqués, et rien ne semblait devoir freiner cet élan irrépressible vers ce qui apparaissait comme un paradis technologique. Mais bientôt les premiers signes avertisseurs se manifestèrent. Rappelons-nous du naufrage de ce titan des mers, le Titanic, que l'on disait insubmersible mais qui sombra pourtant à cause d'une erreur humaine. C'est de ces événements que naquit l'idée que peut-être la technologie ne réussirait pas à résoudre tous les problèmes reliés à la réalisation de systèmes de transport totalement sécuritaires.

La nostalgie éprouvée à l'égard de cette époque dite « belle » ne doit pas nous faire croire que notre époque à nous est comparativement moins belle. Au contraire, le fait est que les systèmes de transport modernes sont plus sûrs, plus économiques et plus efficaces que jamais auparavant. Mais, pour en arriver là, il a fallu accepter l'idée que les machines et les fonctions des opérateurs sont très complexes et que nous ne réussirons pas par la seule technologie à réaliser des systèmes de transport efficaces à 100 p. 100. Il nous a fallu comprendre tout d'abord que l'élément humain fait partie intégrante de tout système, ensuite que cet élément humain est limité dans ses sensations, ses perceptions, ses connaissances et ses performances et, enfin, qu'il faut tenir compte non seulement de ces limites dans toutes les circonstances prévisibles, notamment les situations de stress, d'ennui et de fatigue. Il nous a fallu admettre aussi le fait que la présence de cet élément humain dans la boucle homme-machine oblige l'ingénieur à innover dès qu'il s'agit de concevoir et de réaliser une machine quelconque, et à innover encore pour trouver des méthodes de sélection, de formation et d'évaluation qui garantissent qu'il y a adaptation entre l'opérateur et la machine qu'il doit faire fonctionner. En d'autres termes, ce que nous, ingénieurs, avons dû finir par comprendre, c'est qu'il est de notre intérêt de collaborer avec cette faune étrange qui se fait appeler ergonomistes. À dire vrai, un tel revirement ne fut pas pour nous ingénieurs une mince affaire, sachant à quel point nous tenons à nos prérogatives et à nos habitudes.

Le simulateur de pilotage, voilà un très bel exemple du principe énoncé plus haut, à savoir l'innovation dans le domaine de la formation et de l'évaluation des opérateurs et dans celui de la conception des

machines qu'ils mettent en oeuvre. Le premier de tous a été le fameux Link Trainer, issu de la Deuxième Guerre mondiale et du besoin urgent pour des pilotes, c'est-à-dire des opérateurs, pour faire fonctionner la plus complexe des machines d'alors, l'avion de combat. Primitif, il le fut, d'après nos critères modernes, mais il accéléra considérablement la formation de milliers de pilotes. La technologie, elle, n'en resta pas là. Elle évolua rapidement, menant à l'ordinateur numérique remplaçant l'analogique, d'abord pour le calcul des lois de l'évolution en vol, ensuite pour permettre la réalisation de fonctions aussi exigeantes que la restitution de scènes visuelles et la création de sensations dynamométriques d'un réalisme poussé. Les systèmes y gagnèrent en fiabilité, réalisme et universalité.

La technologie est maintenant si achevée que, l'argent aidant, nous, ingénieurs, avons la possibilité de créer par la simulation un environnement que rien ne distingue du réel. J'irai jusqu'à dire qu'un pilote de ligne qui n'a conduit en tout et pour tout qu'un simulateur de pilotage moderne peut prendre en charge aussitôt après l'avion de ligne que le simulateur est censé représenter et le faire voler en toute sécurité. De même, il est possible d'utiliser les résultats d'expérimentations sur simulateur de pilotage pour mettre à l'épreuve le prototype d'un nouvel avion de transport. Enfin, en cas d'accident aéronautique, le simulateur de pilotage permettra de reconstituer les événements ayant mené à l'écrasement. Tout cela est bien impressionnant, et il semble que la technologie ait fini par l'emporter sur le reste. Cela est peut-être vrai, mais jusqu'à quel point?

Pourtant, il reste encore des doutes lancinants sur notre capacité de tout résoudre par un apport purement quantitatif, technologie plus capitaux, plutôt que par un apport qualitatif, et par qualitatif je fais allusion à la collaboration de nos collègues les ergonomistes. Là-dessus, voici quelques situations technologiques où leur collaboration est indispensable :

- Les simulateurs de pilotage coûtent très cher. En aéronautique, cette cherté est acceptée, car ils sont à toutes fins utiles irremplaçables. Mais qu'en est-il des autres modes de transport où l'apport d'un simulateur, bien que fort utile, reste inabordable ? Il faudra donc envisager des simulateurs moins performants. Mais, alors, où couper ? De combien faut-il réduire le réalisme du rendu, où économiser ?

- Même avec la technologie actuelle, il est impossible de restituer par la simulation certaines situations de haute criticité : ambiance de fortes accélérations sur de longues durées ou état de stress accompagnant une situation d'urgence. Dans ce cas, que faire ? Trouver de nouveaux « trucs » astucieux et crédibles ? Mais comment ?

- Autre problème, l'analyse des performances d'un opérateur. Toutes les techniques actuelles d'analyse du comportement, fondées sur des réactions manifestement béhavioristes, pèchent par leur imprécision. Serait-il possible d'élaborer de nouvelles méthodes, plus fondamentales, fondées par exemple sur la mesure directe des fonctions cérébrales et leur exploitation ?

- Il est certain que les applications du simulateur à l'apprentissage et à la recherche sont devenues aussi nombreuses que variées, et que de nouvelles, comme l'apprentissage de tâches partielles, font leur apparition. Mais qu'en est-il des autres utilisations, tout aussi innovantes, que sont la sélection d'opérateurs et l'apprentissage individualisé ?

De toute évidence, l'exploitation de cette nouvelle technologie du simulateur de pilotage, dont les applications promettent d'être de plus en plus nombreuses et intéressantes, soulève beaucoup de questions, auxquelles nous, ingénieurs, ne saurions apporter de réponses satisfaisantes sans la collaboration de nos amis les ergonomistes.

Cela explique que le thème même de notre séminaire soit celui du simulateur et que le séminaire a été organisé pour stimuler la réflexion sur les perspectives que cet outil offre dans le domaine de l'apprentissage et de l'analyse des performances. Espérons que les perspectives de concertation et d'information se réalisent et que les participants y trouvent des éléments de réponse de manière à assurer à ce séminaire le grand succès qu'il mérite.

SESSION 1

Design, Interface & Vehicle Environment Considerations

Chair: *Pat Foley*
University of Toronto
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ATELIER 1

Conception, interface et environnement du véhicule

Présidence : *Pat Foley*
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Measurement and Prediction of Operator Information Processing Load

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Abstract

The assessment of an operator's information processing load when interacting with some job of work is a fundamental requirement of systems design. This requirement has been institutionalized in the concept of operator "workload" and more recently in the idea of "situational awareness." This paper summarises experiences at DCIEM in the investigation of multivariate subjective rating scales for measurement of operator load, and the use of analytical procedures based on task network modelling for load prediction.

Résumé

L'évaluation de la somme d'informations que doit traiter un opérateur dans l'exécution d'une tâche constitue une exigence fondamentale de la conception de systèmes. D'abord assimilé à la notion de « charge de travail » de l'opérateur, ce paramètre est depuis peu exprimé par l'idée de « charge situationnelle ». Cet article rend compte des travaux effectués par l'IMCME sur des échelles de cotation subjectives multivariables pour la mesure de la charge perceptive et mentale de l'opérateur, et l'utilisation de méthodes analytiques fondées sur l'établissement d'un modèle réticulé de la tâche aux fins de prévoir cette charge.

1. Introduction

Despite continuing problems of definition and measurement (e.g. Gopher and Donchin, 1986), the evaluation of operator information processing load (in the context of operator workload or operator mental load) is a subject that has occupied researchers over many years. Central to the interest in this subject are 2 notions: firstly different tasks make different demands on human information processing resources, and secondly the human information processing system is in some way resource limited. Together these ideas suggest the possibility that when task demand exceeds resource capacity, "operator overload" might occur with implied decrements in system performance. The nature of a "cognitive resource" is not clear, although Wickens (1980) provides a structural model in terms of his multiple resources theory (i.e. resource domains associated with the stages of processing, the modalities involved and the way in which information is encoded), while Kantowitz and Knight Jr. (1976) speak of resources in terms of processing effort, various forms of memory capacity and communication channels. Despite the lack of a clear definition of a processing resource, it seems reasonable to accept that the human information processing mechanism is limited both by the amount of information which can be handled at any one time (memory limited) and by the rate with which processing can take place (computationally limited).

From a systems design point of view, it has been argued that the need to evaluate operator load comes from: a desire to assess task difficulty (e.g. Gopher and Donchin, 1986); a requirement to assess an operator's resource or capacity expenditure (e.g. O'Donnell and Eggemeier, 1986); a requirement to provide a basis for comparison between competing designs and to ensure that performance requirements are met (e.g. Hendy, Campbell, Landry and Hamilton, 1989); and the goal of maintaining operator performance in periods of sustained effort (e.g. Gartner and Murphy, 1976). Although this argument is framed in terms of assessing resource "expenditure", it is the operator's "reserve" capacity that is critical in determining the ability to take on additional tasks. Reserve processing capacity, together with an adequate mental model, are likely to be central in determining an operator's potential to perform in emergency or novel situations. While the quantity and difficulty of information being processed by the operator may determine the demand for processing resources, the "quality" and "relevance" of the information are additional factors in determining the operator's understanding of the system state or "situational awareness" (Taylor, 1988). With an increasing focus on decision making tasks in many modern systems, the concept of situational awareness is gaining importance as a criterion in systems design, and is to some extent replacing the workload paradigm. Yet despite this changing emphasis, the assessment of operator information processing load remains an important aspect of systems design,

whether through the guise of operator "workload" or through the consideration of "situational awareness."

If we are to test claims that new technologies and innovations in human-machine design reduce "workload" (e.g. Chechile, Fleischman and Sadoski, 1986; Robinson and Eberts, 1985) or increase "situational awareness" (e.g. Hollister, 1986; Smyth, Malkin and Bellis, 1989), then we must find and validate ways of measuring or predicting these state variables during the performance of specific operator tasks. Methods to measure or predict operator information processing load abound. They can be categorized in a variety of ways (e.g. Eisen and Hendy, 1987), including: behavioural methods (subjective opinions, primary task performance, spare capacity techniques etc.); analytical methods (task network simulation, control theoretic, queueing models etc.); and physiological correlates (ECG, EEG, evoked cortical potentials etc.). This paper focuses on experience at DCIEM in the measurement of operator load through the use of multi-factor subjective rating scales, and on the prediction of operator load by analytical procedures using task network modelling.

2. Subjective Measures

Subjective measures of operator load have been found to be as good as, or better than, a variety of objective measures in many applications (Casali and Wierwille, 1984). In the last 10 years, 2 rating scales have gained dominance in the area of subjective workload measurement. They are the NASA Task Load Index or TLX (Hart and Staveland, 1988) and the Subjective Workload Assessment Technique or SWAT (Reid and Nygren, 1988). Both scales have the desirable characteristic of multi-dimensionality, but otherwise they are different in their construction and implementation (e.g. see Hendy et al., 1989). Work at DCIEM has favoured the use of the NASA TLX because of its higher dimensionality (6 scales versus 3 scales), its potentially greater sensitivity (21 point scales versus 3 point scales) and the relative simplicity of the scaling technique for combining the individual scale values into an overall value of operator load (15 paired comparisons versus the rank ordering of 27 items). The NASA TLX, and its predecessor the NASA Bipolar scale, have been found to perform as least as well as SWAT in several applications (e.g. Byers, Bittner, Hill, Zaklad and Christ, 1988; Vidulich and Tsang, 1986).

The NASA TLX consists of 6 scales ("Mental Demand", "Physical Demand", "Temporal Demand", "Effort", "Performance" and "Frustration Level"). Each scale is divided into 20 equal intervals with the verbal anchors "Low" and "High" (or "Good" and "Poor" in the case of "Performance") at each end. Scale administration consists of 2 phases, namely a task evaluation phase and a scale development phase. In the scale development phase subjects are asked, in a series of paired comparisons, which of 2 individual scales ("Mental Demand" or "Frustration Level", "Physical Demand" or "Performance", etc.) contributed most to their perception of workload. All possible pairs are considered. These paired comparisons are used to develop a set of weights from which the judgements on the 6 individual scales can be combined into an "overall workload" score. Weights are calculated by simply counting the number of times any 1 scale is considered to be more important than any other. Overall workload is computed from the weighted average of the individual scale values (TLX, 1986). This method of computing an overall workload score, while simple and pragmatic, lacks the firm psychometric basis of the scaling technique used in SWAT.

Rather than use the simple method recommended for the weight calculation in the TLX, the method of paired comparisons can be used to develop weights from Thurstonian scaling (Guilford, 1954) which does have a basis in psychometric theory. Alternatively, if the individual scale factors are thought of as a series of vectors in multivariate space (Senders, 1979) then a vector sum, say based on weights derived from the first principal component of the data (Dillon and Goldstein, 1984), may be more appropriate than a model that ignores the high degree of intercorrelation often found in these data (e.g. Hart and Staveland, 1988; Hendy et al., 1989). From data gathered in 2 independent studies which used the NASA TLX and a TLX-like scale, the performance of these multivariate scales was examined with emphasis on test-retest reliability and the effects of different scaling methods on predicting operator's self reported "global workload." A summary of the principal findings from these two studies follows. For more details see Hendy et al. (1989).

In the first study, NASA TLX and global workload ratings were obtained from 4 pilots after flying night simulated boat approaches and after performing standard instrument approach procedures in the CH-113 "Labrador" helicopter (Hameluck and Stager, 1989) as part of an evaluation of a novel attitude display (the Peripheral Vision Display or PVD). In the current analysis of the PVD data, only observations for individual flight segments of each approach were analysed. This contrasts with an earlier analysis (Hendy et al., 1989) which included data from an assessment of the approach as a whole. In the second study a modified scale, based on the

TABLE 1
Product moment correlations between reported "global" workload ratings and "overall" workload predictions, using various scaling procedures for combining individual scale data into a single value
(i.e. weights based on the standard procedure for the NASA TLX, weights calculated from Thurstonian scaling, and weights derived from the 1st principal component of the individual scale ratings)

	PVD Study			Klowa Study		
	Global	Standard	Thurstone	Global	Standard	Thurstone
Standard	0.866			0.632		
Thurstonian	0.851	0.992		0.621	0.994	
PCA	0.822	0.946	0.957	0.648	0.973	0.975
	(220 observations)			(91 observations)		

NASA TLX, was used to examine the workload of CH-136 "Klowa" crews (4 Pilots, 3 Observers) engaged in low-level helicopter operations. For the modified scale, ratings were obtained along the dimensions "Task Complexity", "Activity Level", "Mental Effort", "Physical Effort", "Anxiety Level" and "Performance." Global workload ratings were obtained using the method of magnitude estimation (Gopher and Braune, 1984). For the data reported, the magnitude estimation ratings were normalized using z-scores. In both studies the scaling procedure for weight calculation, based on a simple count of preferences from the paired comparisons, gave overall workload predictions which correlated highly with those obtained from Thurstonian scaling and the principal component analysis (see Table 1). Overall workload scores calculated by the 3 weighting methods were generally equivalent.

In light of the high intercorrelations between the overall workload values provided by the 3 methods of weight calculation (Table 1), there is little to choose between the methods as measures of "overall operator load." It is concluded that the simple scaling procedure developed by its originators for the NASA TLX, performs as well as the psychometrically-based Thurstonian method of weight calculation. Similar experiences have resulted from studies with SWAT, in which much simplified scaling procedures performed as well as the complicated conjoint analysis which is a feature of this metric (Biers and Masline, 1987; Biers and McInerney, 1988). Of greater practical significance is the possibility that principal component analysis can provide weights for combining the individual scale data into a single workload value, thereby eliminating the need for a separate scale development phase involving the operator's participation. In stating these conclusions, the broader issue of the need/desirability of combining multi-variate data into a uni-dimensional measure is ignored (for a more detailed discussion of this issue, see Hendy et al., 1989).

3. Task Network Simulation

A number of analytical techniques exist as a basis for predicting operator task load (for a recent review, see Linton, Plamondon, Dick, Bittner and Christ, 1989). Perhaps the most versatile techniques are those based on task network modelling (Meister, 1985). Task network modelling produces a simulated task time-line of the operator's job. Such an analytic procedure can be used early in the design process, before hardware exists and before manned simulation is possible. The starting point for a network model is a detailed analysis of the operator's tasks, providing such data as task duration, task dependencies and sequence of task performance. Through the use of a Monte Carlo process, task completion times can be chosen stochastically over a number of runs of the simulation, producing a range of simulation outcomes. For example, if the network contains multiple branches, different concurrent task combinations may result from run to run, in addition to variations in the total time for job performance. Task network simulations can be run under a number of software packages including SAINT (Wortman, Duket, Seifert, Hann and Chubb, 1978), Micro SAINT (Micro SAINT, 1987) and SLAM (Pritsker, 1986).

The simulated task time-line does not in itself provide a measure of operator load. Some type of human information processing model must be added to the task network to turn the time-line information into a prediction of operator information processing demand or performance (for reviews of common models for task network simulation, see McMillan, Beevis, Salas, Strub, Sutton and Van Breda, 1989; Meister, 1985; Wickens, Harwood, Segal, Tkalcevic and Sherman, 1988). Generally, operator resource demand can be assessed in 2 domains, namely the intensity domain (amount of attentional resource) and the time domain (rate of processing). One of the simplest resource demand models is the time-line model. This is based on the classical time-line approach to operator load which simply tallies the amount of time the operator is occupied with tasks, and compares that figure with the total amount of time available. Most other models fall into the intensity domain classification, and attempt to make an assessment of the amount of attentional resource allocated to each task. The intensity domain models can be distinguished both by the degree to which they attempt to quantify the amount of attentional resource demanded by a task, and to the extent that they proportion a resource penalty for multiple concurrent task performance. W/INDEX (North and Riley, 1989), which assumes multiple differentiated resources, represents one of the more complicated models of this type.

Task networks of crew activity in the CH-136 "Kiowa" were produced, for 13 distinct low-level helicopter mission segments (Hendy, Campbell and Schuck, 1990). Workload ratings were gathered using a modified version of the NASA TLX workload scale (see previous discussion on the "Kiowa" study). Overall workload predictions were calculated for the 13 mission segments, averaged over 100 runs of the simulation, using the time-line model and 4 intensity domain models to assess load. Mean, maximum and range values of predicted operator load were obtained from each run. The 13 segments were ranked on the basis of the crew's overall workload assessments from the TLX-like scales and compared to the rankings obtained from the simulations, using Kendall's rank correlation coefficient. Overall the intensity domain models provided better predictions of operator reported workload than the time-line model. The best predictions came from an assessment of the maximum attentional resource demand in what is expected to be the operator's most heavily loaded channel, namely the psychomotor channel for the Pilot and the auditory channel for the Observer (see Table 2). No other clear pattern emerged from the results.

TABLE 2
Correlation between workload predictions from the task network simulations and overall workload scores

Model	Non-Parametric		Parametric	
	Tau	Alpha	r	r sqd.
Pilot				
DAD(P)_max	0.44	0.02	0.66	0.44
DAD(V)_mean	0.44	0.02	0.55	0.30
TAD	0.33	0.06	0.46	0.21
DAD(P)_mean	0.31	0.07	0.13	0.02
DAD(A)_max	0.29	0.09	0.46	0.21
Observer				
DAD(A)_max	0.51	0.01	0.54	0.29
DAD(C)_max	0.51	0.01	0.47	0.22
DAD(C)_range	0.45	0.02	0.44	0.19
DAD(A)_range	0.37	0.04	0.43	0.19

Note: (1) DAD = Differentiated Attentional Demand (attentional demand in each channel)
TAD = Total Attentional Demand (the sum of the attentional demands over channels)
AL = Activity Level (number of tasks per unit time)
(2) V = Visual, A = Auditory, C = Cognitive and P = Psychomotor channels

4. Discussion

Our experience to date with NASA TLX-like scales is that the choice of a scaling method based simply on a count of preferences from paired comparisons is warranted, despite its lack of a firm basis in psychometric theory. Secondly, it is concluded that principal component analysis is a viable procedure for computing a vector "average" of multi-variate, correlated data within the context of estimating operator load. Although caution should be exercised in treating as uni-variate what most researchers in this field regard as multi-variate, it would seem that subjects do have some perception of their total commitment of resources during a job, as evidenced by the correlations between subjects' global workload ratings and the overall workload estimates produced from the individual rating scale values. Consistently, substantial correlations are found between the values from the individual scales used to assess the components of workload, suggesting that there is some general or fundamental factor(s) driving these ratings.

The alternative to the use of a single overall workload value should not be simply to use each of the individual scales as separate uni-variate estimates of load. Although this approach can be used to obtain some information about the likely source of an overload, it denies the possible existence of underlying factors driving the demand for resources (say within the domains of Wickens multiple resource theory). Unless the scales truly tap independent aspects of the human information processing system, they should be used in combination in some way. Although the call for multi-variate methods for dealing with the concept of operator load is old, few (if any) specific solutions have been offered for dealing with the "pattern" of load as suggested by Sanders (1979).

The use of the first principal component reported in this paper merely transforms the multi-variate problem to a uni-variate problem rather than dealing with the data space holistically. A problem arises when 2 or more situations have to be compared for which the principal component solutions are demonstrably different. Unless the first principal component is endowed with some physiological or psychological interpretation (total activation, energy etc.) it is doubtful that the situations should be compared solely on the basis of the magnitude of their principal components. As an alternative, a "stress" function might be computed that represents the disparity between the vector fields as a whole. Something like Kruskal's STRESS index (Dillon and Goldstein, 1984), used as a measure of fit in many multi-dimensional scaling techniques, may be a reasonable model on which to base the computation.

There appears to be relatively little information on task network simulation published in the open literature, with information concerning the validation of information processing models for workload/performance prediction being particularly scarce. Perhaps the most accessible body of work comes from the University of Illinois. Wickens and his co-workers (e.g. Wickens et al., 1988; Larish, Wickens, Segal, Sherman and Contorer, 1989; Wickens, Larish and Contorer, 1989) have investigated a number of intensity domain models as predictors of subjective workload and performance in a simulated low-level helicopter task called TASKILLAN. A clear pattern is yet to emerge. Over 3 reported studies, the most consistent result has been the performance of the total attentional demand model to predict subjective workload. This model derives from the work of Aldrich, Craddock and McCracken (1984) for the LHX project. This procedure represented a major break from the more traditional time-line approaches, and requires estimates of attentional demand in the visual, auditory, cognitive and psychomotor channels which is then simply summed to produce a single measure of information processing load.

Our "Kiowa" simulations have provided evidence for the superiority of intensity domains models over time domain models for the specific application studied, but have not established an unequivocal dominance of one intensity domain model over another. There is an indication that concentrating on the most heavily loaded channels (i.e. a differentiated attentional demand model) can provide reasonable predictions. In all the intensity domain models applied to date on the "Kiowa" simulations, no specific penalty is applied when tasks are performed concurrently. It is hoped to implement a full differentiated multiple resources model (similar to W/INDEX) in future analyses.

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Human Error on the Road: Implications for System Design

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Abstract

The nature of the driving task is examined, with emphasis on the abilities and limitations of the driver. One of the most important driver abilities involves taking in and processing information from the roadway environment and from within the vehicle and making quick decisions and responses based on this information. The special difficulties of the elderly driver are outlined. The need to take into account various driver characteristics in the design of roadways and vehicles is discussed.

Résumé

L'auteur examine la tâche d'un conducteur de véhicule automobile, en se penchant plus particulièrement sur les capacités et les limites du conducteur. Les capacités qui comptent le plus dans la conduite automobile sont l'aptitude à percevoir et à traiter l'information contenue dans l'environnement routier et à l'intérieur du véhicule, et à prendre des décisions et à réagir rapidement sur la base de cette information. L'article souligne à cet égard les problèmes particuliers auxquels fait face le conducteur âgé. Il fait également état de la nécessité de tenir compte des diverses caractéristiques des conducteurs dans la conception des routes et des véhicules.

The Driving Task

Driving is a very complex task, involving a variety of skills, the most important of which are the taking in and processing of information and making quick decisions based on this information. Although a great many models and schematic representations of driving can be found, most involve all or some of the following human abilities and characteristics: basic perceptual-motor skills, attention and information processing skills, physical and psychological states of the driver, and several modulating factors such as driver age, experience, personality, motivation and fatigue.

The importance of correct and rapid information processing is well illustrated in the perception model proposed by Vanstrum and Caples (1972). It includes a "zone of committed motion projected ahead" of the vehicle, composed of four segments: (1) distance travelled during minimum perception time; (2) distance travelled during minimum decision time; (3) distance travelled during minimum reaction time; and (4) minimum committed motion area of the vehicle after a response has been made to turn or stop. Since driving is dynamic in nature, the various points, the committed zone and the driver's perception of these relationships change continually.

Perceptual error can result from a number of factors (e.g., alcohol, fatigue, inexperience, inattention). According to Vanstrum and Caples perceptual error is the proximate cause of most preventable traffic accidents. Prevention can be accomplished by increasing the margin of error and/or decreasing the perceptual error. The latter error can be reduced by making hazards more visible and increasing drivers' sensory and perceptual abilities. The need for good information processing skills is evident here.

The driving task can also be broken down into three main elements – control, guidance and navigation, as outlined by Alexander and Lunenfeld (1975).

Control involves the driver's interaction with the vehicle, in terms of speed and direction (accelerating, braking, steering). Relevant information comes mainly from the vehicle and its displays.

Guidance refers to maintaining a safe path and speed and keeping the vehicle in the proper lane on the road. Information comes from roadway alignment, hazards, traffic control devices, and other vehicles and pedestrians using the roadway.

Navigation means planning and executing a trip from one location to another. Navigational information comes from maps, guide signs, landmarks, etc. The first of these has the highest priority, in the event of an emergency, while navigation has the lowest. Performance is relatively simple and overlearned at the control level, but information handling is more complex at the other levels.

The Design Driver

A great many human characteristics and individual differences influence the ability of drivers to use the roadway system properly. In order to appreciate these the concept of the "design driver" needs to be understood. This phrase refers to the range of drivers whose abilities and limitations need to be taken into account in designing roads, vehicles, traffic control devices, road maps, etc. It may be considered in terms of the "reasonable worst case". Traffic engineers often use the 85th percentile as a cutoff for determining things such as speed limits and decision sight distance. However, it must be kept in mind that there is no such person as the "average driver" or the typical 85th percentile driver, as any individual will vary with respect to different abilities. The driver with very good vision may have average hearing and poor motor coordination.

Information Processing and Perception

Over the past few decades driving has become much more of a cognitive task as the physical aspects of driving (e.g., braking, steering, shifting gears) have become easier and more complex and greater amounts of information are presented to the driver. It is generally agreed that about 90% of the information a driver receives is visual and the importance of vision is reflected in the emphasis placed on it in driver licensing tests. Approximately 40% of all traffic accidents involving human error have as contributory factors difficulties in information processing or perception (Treat, et al., 1977).

It may seem obvious that basic visual sensory abilities, such as acuity, depth perception and peripheral vision, are all important to the driving task, but a large study in California (Henderson and Burg, 1974) failed to find a consistent relationship between these abilities and collision rates, except for dynamic visual acuity and central movement in depth, the ability to detect the rate of change of the size of the image on the retina, an essential ability when overtaking other vehicles or approaching a hazard on the roadway.

A fundamental component of this approach is the concept of expectancy. Drivers operate with a set of expectancies -- freeway exits in Canada will be on the right side of the roadway, advance warning will be given of hazards on the road, other drivers will obey traffic rules -- and if these expectancies are violated there is the potential for an accident. Therefore, information from traffic control devices, the roadway environment, etc. must be provided when and where it is expected.

What are the important aspects of perception and information processing? The evidence suggests that the main factors involve looking in the right place at the right time -- i.e., paying proper attention. Tests on selective attention have been found to correlate well with accident rates. In-depth accident investigations have shown that nearly half of the human causal factors in accidents relate to attention e.g., internal distraction, inattention, preoccupation (Treat, et al., 1977).

As drivers gain experience they get better at scanning the roadway environment and at ignoring irrelevant information. Eye movements change from narrow scanning and looking just ahead of the vehicle to sampling more widely as driving experience increases (Mourant and Rockwell, 1972). This may be one reason why new drivers have difficulty in complex driving environments. Proper allocation of attention has become more difficult in the last decade or so, as the driver is getting overloaded, with more complex dashboards in vehicles and more traffic signs to read.

A related issue is "spare mental capacity" (the ability to do a number of things at one time), which has been found to be related to accident record -- those with more of this capacity have fewer accidents, as they are able to attend to and process more than one source of input at a time (i.e., they are better at time-sharing). Laboratory research (Lim and Dewar, 1988) suggests that drivers with low spare mental capacity are more likely to have accidents.

Reaction Time

One of the human factors often cited by traffic engineers concerned with safety is perception-reaction time (PRT), or how quickly a driver can see and respond to an emergency situation. A good deal of research has been done on this topic, but there is still not complete agreement on what PRT is appropriate for use in the design of roadways and traffic control devices. The concept of decision sight distance is an important part of roadway engineering, as it relates to stopping, steering and overtaking. Adequate sight distance depends, of course on vehicle speed and size as well as driver PRT.

The PRT used for design standards by the American Association of State Highway and Transportation Officials (AASHTO) was derived from research done some time ago and includes 1.5 sec. for perception and decision and 1.0 sec for making the response, for a total of 2.5 sec.

The nature of driver PRT is often not appreciated by those who use the concept. The total time to complete

an appropriate response involves the following elements: detection, identification, decision, response execution, and time for the vehicle to respond. All of this takes considerable time. This time is increased under conditions where the hazard is unexpected (which is most of the time in emergency situations), the driving scene is visually complex or dark, and when the driver is impaired, distracted by other components of the driving task, not paying attention, fatigued, or elderly. Hence the need to take into account not the "average" driver, but the one whose performance is much below that of most others on the road.

The complexities of driver reaction time have been described in detail by Triggs (1982), who points out that a PRT in excess of 2.5 sec. should be the standard in design of roads, traffic control devices, etc. He examined PRT in a variety of driving situations ranging from braking to traffic signs and the presence of police to emergency situations (e.g., braking by a lead vehicle). The 85th percentile reaction times to brake ranged from 1.26 sec. to over 3 sec., and 7 of the 12 situations tested produced times greater than 2.5 sec., suggesting that the standard of 2.5 sec. is too low.

An examination of the current standards for PRT was carried out by Hooper and McGee (1983). On the basis of available literature on the topic they determined that the current time of 2.5 sec. was too short, in view of the complexities of the driving task. They suggest 3.2 sec. as a more reasonable figure.

Elderly Drivers

The world of the elderly driver is very different from that of the young person. The one limitation of elderly drivers which has probably received the most attention by the traffic safety community is their failing sensory and information processing capacity. The abilities known to deteriorate with age will be outlined briefly as they might relate to traffic safety.

Statistics have indicated that accident rates increase after the age of 65 and that specific types of violations (involving traffic signs, right of way and turning left) are more common among the elderly. In addition, most accidents occur in ideal driving conditions, as the elderly drive much less at night, in heavy traffic and in poor weather.

Perhaps the most obvious limitation among the elderly are visual problems. The following are the most relevant ones with respect to driving:

- decrease in acuity starting at age 40
- less light gets into the eye as pupil size decreases and lens yellows with age (about 1/3 of the light that enters the eye of a typical 20 year old)
- glare sensitivity increases and recovery takes longer
- contrast sensitivity is poor (contrast must be about 3 times as great for the elderly)
- size of the visual field decreases with age
- night vision is reduced
- more time is required to change focus
- eye movements are slower

There is obviously a need to pay greater attention to the information needs of the older driver and to take these into account when designing and implementing all aspects of the system-vehicles, roadways, maps, traffic control devices, and even re-education programmes and licensing standards.

Vehicle Design

The increase in the cognitive components of the driving task are no better reflected than in advances in the design of in-vehicle information systems (e.g., dashboard displays). As a result there is potentially available to drivers a plethora of information, much of which is of dubious relevance to the driving task. Changes in these systems are progressing at a much faster rate than is the information processing ability of the average driver. This is particularly true in the case of elderly drivers, many of whom do not like the new "high tech" displays seen on late model vehicles. The basic problem (or potential problem) here is the presence of unfamiliar information (typically in the form of novel pictographs to indicate various displays and controls in the vehicle) and information overload (Dewar, 1988).

The great variety of designs and placement of controls makes it difficult to find them within a reasonable time. The location of in-vehicle displays and controls often confuses drivers, especially in unfamiliar vehicles (e.g., rented cars). A study by McGrath (1975) found that operating problems in rented cars occurred with climate controls (23%), shoulder harness (20%), seat belts (15%) and windshield washers (19%). In a reaction time experiment drivers often took long times to find and activate vehicle controls. Frequently the controls were not where drivers expected them to be. Such delays or the activation of the wrong controls can have disastrous consequences when driving at high speed. Greater uniformity of layout would obviously be better for drivers.

One possible solution to the use of many displays spread around the dashboard is the use of a single CRT to display a number of information sources (as now used in many modern jet aircraft). Snyder and Monty (1985) compared the conventional display format (with a dedicated display for each control) in a car with three versions of an electronic display with a touch addressable control panel. Measures taken while driving were lane keeping, speed control, braking frequency, eye movements to the displays and performance on specific in-vehicle information gathering and control tasks (e.g., manipulate the radio, report trip information). Performance was consistently poorer on the three electronic displays, as compared with the traditional approach. In addition, performance was worse and glance durations longer for older drivers. This latter finding is important, in that the drivers who are most likely to be able to afford vehicles with such displays will be older drivers (at least initially).

Lack of uniformity also presents problems in understanding the meaning of symbols on dials and controls. There are various versions of the same message, and some do not look like what they are intended to represent. Elderly drivers, in particular, have problems here. As more information becomes available in vehicles the problem will get worse, unless an effort is made to standardize the presentation of symbols. There will also be the general problem of information overload for drivers, who may become distracted or confused by displays of useless and complex information.

The device of the future (already available on the market) is the in-vehicle navigational system which will provide drivers with an electronic map (a TV version of paper maps which most of us currently rely on to navigate). The potential for accidents due to distractions from using electronic maps, cellular phones, computers, intelligent vehicle information, etc. is very real, but little is known about this problem to date.

Conclusions

As can be seen from the discussion above, driving is a very complex task and in many ways is becoming more complex as traffic increases, amount of roadway and vehicle information increases and the driving population ages. The abilities and limitations of drivers, representative of the actual driving population, must obviously be taken into account in any efforts to research driving behavior, whether on the roadway or in a laboratory with simulators. The simulation of human behavior is very difficult, especially for something as involved and variable as operating a motor vehicle.

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Le rôle des ingénieurs de locomotive dans l'efficacité et la sécurité du système ferroviaire : éléments de R&D de simulateurs[1]

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Résumé

Cet article brosse un tableau général des problèmes que pose la conduite de train du point de vue de la sécurité du système ferroviaire. Les éléments discutés sont tirés d'une recherche d'ergonomie en cours portant sur l'activité des ingénieurs de locomotive en situation réelle de travail; il s'agit d'une recherche centrée sur la dimension cognitive de l'activité. Après avoir exposé brièvement la méthodologie et les principaux résultats de cette recherche, des liens entre la situation de travail des ingénieurs et la prise de décision à risque sont dégagés. L'exploitation que l'on peut faire de telles données pour orienter la R&D de simulateurs dans le but d'améliorer la sécurité du système est discutée; trois exemples sont développés.

Abstract

This paper outlines the security problems created for the railway system by freight train driving. The elements discussed are drawn from current research focussed on the cognitive aspects of locomotive engineers' activities in real situations. After a brief statement of the methodology and the main results of this research, the relationship between the engineers' work situation and their decision-making in hazardous situations is explained. The use of these data to develop simulator R&D aimed at improving railway security is discussed, and three examples are developed.

1. Introduction

La connaissance des problèmes que pose la conduite de train est essentielle au choix des avenues de développement et d'utilisation des simulateurs de conduite dans un but d'améliorer la sûreté de la circulation ferroviaire. Une recherche d'ergonomie en cours portant sur l'activité des ingénieurs de locomotive en situation réelle de travail a mis en évidence des éléments à ce niveau. Cette recherche est centrée sur la dimension cognitive de l'activité, i.e. sur les processus de raisonnement sous-jacents aux prises de décision et aux actions des ingénieurs. Elle permet de comprendre comment l'organisation et les conditions du travail des ingénieurs déterminent leurs décisions, et d'identifier la nature et les causes des décisions à risque pour la sécurité. Après avoir exposé la méthodologie de la recherche et ses principaux résultats, trois exemples sont développés pour illustrer l'exploitation que l'on peut faire de telles données pour orienter la R&D des simulateurs de conduite.

2. Brève introduction méthodologique

Une étude préliminaire a permis d'explorer l'activité cognitive des ingénieurs, ses liens avec la situation de travail et son rôle dans l'efficacité et la fiabilité du système ferroviaire. Partant, un protocole de recueil de données a été développé en vue d'éprouver ce pré-diagnostic. L'outil privilégié est la verbalisation, par l'ingénieur concerné, de ses raisonnements, à partir d'un enregistrement vidéo de son activité. Les séquences de l'activité choisies pour la verbalisation sont celles qui témoignent d'une prise de décision à risque (ex.: l'oubli d'une restriction de vitesse) ou d'un élément du pré-diagnostic qui n'a pas encore fait l'objet d'une verbalisation. Le protocole de questionnement de l'ingénieur consiste en une instruction de type « penser tout haut » avec relance du chercheur à partir des comportements observables (ex.: la direction du regard) et d'événements se produisant pendant le trajet (ex.: une alarme). Des données sont recueillies pendant une quinzaine de trajets représentatifs des situations de conduite les plus fréquentes et de celles considérées « difficiles »; ces situations sont définies par des combinaisons de facteurs (mode de régulation, type de train, horaire, affectation de l'ingénieur, température et fréquence des travaux sur la voie). Les verbalisations sont

[1] *Cette recherche est possible grâce à la participation de la Compagnie des chemins de fer nationaux (CN), des ingénieurs de locomotive et de leurs représentants de la Fraternité des ingénieurs de locomotive (FIL).*

enregistrées et transcrites. L'analyse des verbalisations et de l'enregistrement de l'activité est réalisée de manière à retracer la dynamique des raisonnements et prises de décision en situation réelle.

3. L'activité réelle des ingénieurs de locomotive

La recherche a mené à la constatation, toujours renouvelée en ergonomie et qui doit servir de principe au développement des simulateurs, à savoir : l'activité réelle des ingénieurs diffère de sa conception théorique. Suivant celle-ci, la responsabilité de l'ingénieur serait de contrôler son train (ce qui suppose de connaître le territoire et les principes de manoeuvre d'un convoi) en respectant les prescriptions, soit :

- les vitesses permises indiquées dans les documents révisés semi-annuellement, mensuellement et quotidiennement et, au besoin, par ordres-radio du régulateur;
- les zones de circulation autorisées et les vitesses permises transmises par le régulateur via les signaux ou par radio;
- les zones à ne pas franchir, occupées par une équipe de travaux, et le contremaître à contacter pour être autorisé à les franchir et savoir à quelle vitesse (indiqué dans le document quotidien);
- ces prescriptions sont par ailleurs répétées aux ingénieurs via des communications entre les membres de l'équipe de train et/ou une signalisation en bordure de la voie.

La détermination de ces « buts » du contrôle n'exigerait pas d'investissement cognitif de la part de l'ingénieur puisqu'il s'agit de « données » à respecter, prédéterminées de manière à assurer une circulation sécuritaire et efficace des trains. En pratique, toutefois, il n'y a pas une telle division stricte des responsabilités : les ingénieurs mettent en oeuvre des stratégies actives de mémorisation, de recherche d'information et d'opérationnalisation de ces prescriptions de même qu'ils participent à l'organisation efficace et sécuritaire de leur parcours et des circulations. Dans la discussion qui suit, nous allons montrer, non sans s'imposer des limites considérables, comment l'activité cognitive réelle des ingénieurs s'organise. L'activité est artificiellement découpée suivant qu'elle concerne le contrôle du train, « d'autres activités », ou l'intégration de ces activités et du contrôle du train dans la dynamique de la conduite.

3.1 Activité orientée vers le contrôle du train

Le problème que pose le contrôle du train pour l'ingénieur comporte quatre aspects :

- déterminer le but du contrôle, quoi faire pour l'atteindre (quelles actions prendre) et quand; du fait de l'inertie d'un train et des limites d'utilisation des freins à air, ces aspects sont planifiés sous la forme d'une séquence de recueils d'information, d'actions sur les commandes et de réactions du train;
- exécuter puis corriger la planification en fonction des écarts constatés ou des informations supplémentaires connues.

L'ingénieur considère ces différents aspects du problème de façon intégrée. Il prend en compte les possibilités, contraintes et risques spécifiques à chaque aspect ou combinaison de ces aspects. Sa décision constitue un compromis qui permet d'optimiser la conduite sur les plans techniques et de l'efficacité de, pour son parcours (en partie ou dans son ensemble) et pour la circulation, sachant que la sécurité est assurée. Considérons quelques exemples :

- Dans une descente, l'ingénieur contrôle son train à une vitesse qu'il sait sécuritaire et qui lui permettra de franchir la montée qui suit sans trop décélérer (gain de temps). Ceci peut aussi permettre d'entrer en voie d'évitement plus tôt et ainsi éviter au train rencontré de ralentir; dans ce dernier cas, le compromis peut être à l'initiative de l'ingénieur ou être suggéré (plus ou moins explicitement) par le régulateur ou les autres équipes de train.
- L'ingénieur prévoit avoir des difficultés à joindre le contremaître par radio. Pour se donner plus de temps pour établir la communication avant d'atteindre la zone des travaux, il maintient la vitesse du train en bas de celle permise. Ceci lui évite d'arrêter puis de repartir le train dans une pente (gain de temps, évite les difficultés de manoeuvres et le risque de casser le train).
- L'ingénieur cherche à savoir avant de voir le signal, comment le régulateur organise les rencontres; avoir l'information plus tôt lui est pratique pour mieux planifier le contrôle du train.

Ces pratiques sont intimement liées à la manière dont l'ingénieur tire partie de son expérience, fait face à la venue possible d'incidents et intègre les multiples facettes de la conduite d'un train en situation réelle.

3.2 Autres activités

La conduite du train implique d'autres activités que le contrôle comme tel. Il s'agit de tâches prescrites (avertissement aux passages à niveau, observation du train dans les courbes) ou d'activités liées à la coopération qui s'établit entre les équipes de train, les régulateurs, les contremaîtres de travaux et les chefs de triage, en vue d'assurer la sécurité et l'efficacité du système; par exemple :

- Le régulateur demande à l'ingénieur de lui indiquer l'endroit précis où sont stationnés des wagons dans telle voie d'évitement lorsqu'il passera à cet endroit.
- Le contremaître attend le passage du train pour obtenir une autorisation de circuler et demande à l'ingénieur d'avertir le régulateur dès qu'il aura passé tel endroit.
- L'ingénieur et le régulateur organisent les manoeuvres à faire pour laisser des wagons dans une voie d'évitement (par ex.: par l'aiguille opposée, en reculant sur la voie principale).
- À l'approche de la gare de triage, point d'arrêt pour l'ingénieur, celui-ci organise avec le chef de triage l'abandon du train (dans quelle voie, s'il y a des manoeuvres des wagons à faire, etc.).

Cette coopération qui, on l'a vu peut influencer le contrôle du train, s'établit du fait que chacun a des rôles différents, dispose d'aspects différents de l'information et de possibilités d'action distinctes mais qui sont à la fois complémentaires.

3.3 Dynamique de la conduite

Comment ces deux aspects de l'activité se présentent-ils dans la dynamique de la situation réelle et quels processus cognitifs sont mis en oeuvre pour composer avec cette dynamique ? La situation réelle se présente comme une alternance de périodes « calmes » et « chargées » d'une durée (en distance et en temps) plus ou moins longue. Du point de vue de l'activité cognitive, cette distinction renvoie à deux types de stratégies interdépendantes jouant un rôle central dans la prise de décision : le travail en temps partagé et l'apprentissage.

Le travail en temps partagé. Il peut s'écouler une demi-heure et l'ingénieur peut franchir une dizaine de milles pendant qu'il organise et réalise son entrée en gare de triage, ses manoeuvres pour laisser des wagons dans une voie d'évitement ou son passage dans une zone de travaux. Pendant ce temps, le contrôle du train et la réalisation des autres activités se poursuivent. Certaines périodes d'un trajet se caractérisent donc par le chevauchement de « cours d'action » i.e. des séquences d'actions et d'événements liés par une même finalité. La gestion de ces chevauchements n'est pas complètement souple : des « butées spatio-temporelles » réduisent la marge de manoeuvre de l'ingénieur (par ex.: sauf à tel endroit il peut être difficile de rejoindre le contremaître, au début de la zone de vitesse réduite il faut actionner le compteur de distance, tel endroit constitue la limite pour prendre action et contrôler le train).

Bien que ces distinctions comportent des zones grises liées à la difficulté de cerner « l'intention » de l'action, les observations montrent que l'ingénieur réussit ou non à gérer ces chevauchements et que cette gestion peut se faire ou non au prix de compromis. Ainsi, il y a échec si la communication radio avec le régulateur et le contrôle du train dans une pente font oublier la présence d'une équipe de travaux en aval; il y a compromis si l'ingénieur exécute un signal non réglementaire au passage à niveau ou laisse diminuer la vitesse du train au profit de sa communication radio avec le régulateur. La possibilité de gérer ou non le chevauchement des cours d'action, avec ou sans compromis, est déterminée par leur « compatibilité propre »; ainsi, si les butées temporelles se présentent au même moment, le compromis est obligé. Elle dépend également de leur « compatibilité cognitive » i.e. le degré avec lequel les différents cours d'action font appel aux mêmes ressources cognitives, en particulier, le degré avec lequel ils s'opèrent sous le contrôle de l'attention.

Attention contrôlée et travail semi-automatique. Le conduite d'un train pendant des sections plus ou moins longues de trajet, ne s'opère pas toujours sous le contrôle de l'attention. Les observations montrent en effet que placé dans certaines situations, l'ingénieur semble disposer de références internes qui lui permettent de « cueillir » immédiatement l'information pertinente et de prendre les actions appropriées de manière rapide, efficace, quasi-automatique et sans efforts perceptibles. Par contre, dans d'autres situations, l'ingénieur ne semble pas disposer de telles références internes et la conduite s'opère sous le contrôle de l'attention.

En fait, l'apprentissage est une propriété essentielle du processus d'adaptation: 1- du contrôle du train, 2- de l'exécution des autres activités et 3- de l'intégration de ces activités et du contrôle dans la dynamique réelle. Tout ce qui affecte la disponibilité d'informations sur les expériences passées concernant l'une ou l'autre de ces trois dimensions joue un rôle dans le niveau d'attention requis pour

l'ingénieur. On comprend aisément que la dynamique d'un parcours s'organise de façon variable et ainsi affecte l'attention requise pour réaliser l'intégration des activités. De même, l'attention requise par chacune des deux premières dimensions, prises isolément, varie.

- **les « autres activités » visant la coordination**

Elles s'opèrent toujours sous le contrôle de l'attention mais à des degrés variables. Les données montrent en effet que les ingénieurs ont tendance à mettre l'emphase sur les coordinations pour lesquelles les conséquences possibles d'un échec sont, pour eux, les plus catastrophiques. Les stratégies mises en oeuvre pour se mémoriser la présence des équipes de travaux sur la voie constituent un exemple typique; ainsi, certains ingénieurs rapportent mettre en oeuvre une stratégie d'autorépétition du type « à chaque signal de canton se répéter la prochaine zone de travaux à franchir ».

- **le contrôle du train**

À ce niveau, on peut distinguer trois grands types de situations: 1- celles qui s'apprennent et a) qui sont apprises ou b) mais qui ne sont pas apprises et 2- celles qui ne peuvent s'apprendre. Les situations 1b et 2 réfèrent aux observations où le contrôle du train requiert de l'attention et où l'ingénieur développe des stratégies :

- pour se mémoriser quoi faire : mettre à la vue « la prochaine restriction nouvelle » qu'il y ait ou non d'autres restrictions à respecter avant, placer la main sur le frein automatique si le dernier signal reçu prescrit un ralentissement;
- pour planifier quoi faire et quand : l'ingénieur met en oeuvre un processus « d'adaptation sécuritaire » i.e. qu'il se réfère à des solutions appliquées dans le passé pour fixer la solution sécuritaire à privilégier dans la situation en cours;
- pour surveiller la planification en vue de la corriger au besoin.

La distinction entre les situations 1 et 2 est importante pour l'analyse de la sûreté. Elle rend compte du fait que certaines situations de contrôle sont apprises ou non, selon l'expérience de l'ingénieur alors que d'autres ne sont jamais apprises, quelque que soit l'ingénieur. Il s'agit de situations pour lesquelles le contrôle du train laisse peu de marge de manoeuvre ou est considéré impraticable par les ingénieurs; par exemple, avoir à conduire un train court et lourd, composé de wagons chargés de matières instables, dans un froid intense (efficacité des freins faible et variable).

L'apprentissage effective et possible joue donc un rôle important dans la fiabilité des décisions de contrôle du train et d'intégration des activités se chevauchant. À l'autre extrême, se trouve toutefois le risque que des décisions inappropriées soient prises par surapprentissage.

La section suivante résume les connaissances que les données d'activité réelle ont permis de dégager quant au rôle des ingénieurs de locomotive dans la fiabilité du système ferroviaire et explore les voies de R&D de simulateurs pouvant contribuer à l'amélioration de cette fiabilité.

4. Activité réelle et sécurité du système

De l'analyse des accidents passés et des données d'activité réelle, notamment des incidents qui ont pu être observés ou qui ont été rapportés au cours de cette recherche, on peut dégager cinq grandes « combinaisons critiques » reliant la situation de travail et le fonctionnement cognitif, présentées dans le tableau de la page suivante (le traitement des données systématiques n'étant pas terminé, ce tableau ne se veut ni exhaustif ni nécessairement représentatif des questions prioritaires).

Deux grandes voies d'intervention sont possibles pour améliorer la convivialité de la situation de travail et de l'activité cognitive des ingénieurs: la formation ou la transformation de la situation de travail. Le simulateur est un des outils utile pour la formation ou la conception. Trois exemples sont développés à partir des problèmes de mémorisation, de contrôle du train et de coordination révélés dans ce tableau. Ces trois exemples sont orientés vers la conception de la situation de travail, la formation étant le sujet central de la seconde journée de ce séminaire.

Exemple 1 : Aide la mémorisation et au rappel des prescriptions au départ de chaque trajet

Malgré les systèmes de rappel prévus (drapeaux le long de la voie et communication de l'équipe) et malgré les stratégies de mémorisation mises en oeuvre par les ingénieurs, on observe des situations où ces prescriptions sont oubliées et certaines opérations connues de l'ingénieur ne sont pas mises en oeuvre. Les données d'activité exposées montrent qu'il faut prendre en compte les lois du fonctionnement cognitif et les caractéristiques de la situation de travail pour en comprendre les causes.

La connaissance des stratégies mises en oeuvre par les ingénieurs « pour se rappeler » ces prescriptions constitue autant d'indices pour le design d'une nouvelle forme de présentation de cette information; par exemple :

« Combinaisons critiques » situation de travail – fonctionnement cognitif	Accidents passés ou incidents observés
1. Situation favorisant une baisse du niveau de vigilance (fatigue, durée du travail, horaire)	Oubli de prescriptions (restrictions de vitesse, présence d'une équipe de travaux, signaux), oubli faisant échouer le contrôle du train (ne pas prendre action au bon moment)
2. Situation favorisant la conduite par surapprentissage	Idem
3. Situation impliquant le chevauchement d'activités incompatibles	Échec à la gestion du travail en temps partagé : oubli ou opérations risquées de contrôle du train (normalement connu de l'ingénieur)
4. Situation de contrôle du train avec faible marge de manoeuvre	Opérations risquées de contrôle du train liées à l'incertitude
5. Situation de contrôle du train sur la base d'une représentation erronée de la circulation	Contrôle du train en fonction de la réalisation d'un mouvement incompatible avec les autres circulations

- fournir une information de départ qui favorise l'encodage et le rappel, notamment, qui met en évidence les différences par rapport aux journées précédentes;
- développer un moyen de rappel indépendant de la mémoire, qui n'interfère pas avec les autres activités (en particulier avec celles s'opérant sous le contrôle de l'attention) et qui soit compatible avec la logique réelle d'utilisation, i.e. qui permet seulement de « se rappeler qu'il faut faire quelque chose » (le détail de ce dont il faut se rappeler peut être consulté sur le document de départ) ce, seulement au bon moment.

L'objectif est de pallier au problème de mémorisation (qu'il soit lié à la fatigue, au surapprentissage ou à l'attention partagée) sans le déplacer. L'utilité du simulateur est qu'il permet de tester l'outil et de préciser un certain nombre de ses caractéristiques ce, avant d'en faire l'installation à grande échelle et sans constituer un risque pour la sécurité. Les données d'activité permettent à ce niveau de définir les conditions que le simulateur doit permettre de reproduire afin de mettre l'outil développé à l'épreuve (par ex.: les situations « chargées » et les termes précis de ces situations).

Exemple 2 : Aide à la planification du contrôle du train

On a vu que la planification était une caractéristique essentielle du processus mis en oeuvre pour contrôler le train; cette planification repose sur la compétence qu'ont les ingénieurs à prévoir les réactions du train en tenant compte d'un ensemble de facteurs, en particulier lors de l'utilisation des freins. Toutefois, dans certaines situations, les ingénieurs ne peuvent développer une telle compétence parce que les réactions des freins sont imprévisibles ou le freinage est impraticable ou laisse peu de marge de manoeuvre; pour reprendre leur expression, ils font « ce qu'ils peuvent » avec le train, non « ce qu'ils veulent ». Typiquement, ces situations sont celles où le train à manoeuvrer est court et lourd et formé de wagons chargés de matières instables; à cela peut s'ajouter des facteurs aggravants tels : un ingénieur peu expérimenté (ex.: affecté normalement comme chef de train) amené à conduire par temps froid, de nuit. De manière à maintenir la flexibilité du système actuel d'affectation des ingénieurs et de formation des trains, on peut penser améliorer l'efficacité du freinage (capacité et stabilité) pour ces situations spécifiques. Est-ce une solution acceptable que d'assigner des locomotives équipées d'un système de frein hydraulique sur ces trains ou faut-il développer un système de freins pour certains wagons plus efficace ? Dans ce dernier cas, ce nouveau système de frein permet-il la conduite dans toutes les situations (trains mixtes, profil de voie, température, wagons chargés et vides, vitesse) ? Le simulateur est le seul outil qui permette de tester les alternatives et d'identifier les solutions efficaces et sécuritaires du point de vue de la conduite.

Exemple 3 : Organisation de la coopération

On a vu que l'efficacité et la sécurité des circulations repose largement sur la coopération qui s'établit entre les régulateurs, les équipes de travaux, les équipes de train et les chefs de triage. Par contre,

ce travail d'équipe peut aussi jouer un rôle dans la prise de décision à risque par les ingénieurs en interférant avec d'autres activités ou en favorisant un contrôle du train incompatible avec les autres circulations.

La division des responsabilités prévue par l'organisation théorique du système pouvait être appropriée si on considère les conditions dans lesquelles elle a été conçue. Mais depuis, différents éléments du système ont changé. En particulier, l'arrivée des communications radio de même que la signalisation des voies ont complètement modifié la dynamique du travail entre les différents individus concernés par la circulation. Les possibilités de coopération (échanges d'informations et coordination des actions) se sont accrues avec la radio mais aussi, les transferts d'informations, autrefois pratiquement inexistants, s'imposent aujourd'hui par la seule présence des signaux, sans qu'aucun effort de recherche ne soit mis en oeuvre. Dans ce nouveau contexte et compte tenu du fonctionnement réel actuel, on peut légitimement se demander si une nouvelle organisation de la coopération et une nouvelle division des responsabilités qui renforceraient les effets positifs de la coopération actuelle sur l'efficacité et la fiabilité du système et réduiraient ses effets négatifs, ne seraient pas plus appropriées. Le développement des simulateurs est alors essentiel pour répondre à toutes les questions que pose une telle réorientation. Le défi ne relève pas de la fiction. À Électricité de France, l'implantation de l'informatique dans les salles de contrôle des centrales nucléaires a amené les organisateurs à se poser des questions de cet ordre soit celles de revoir le nombre d'opérateurs de salle nécessaires et de redéfinir la division des tâches entre opérateurs de salle et rondier. Un simulateur appelé S3C (Salle de Commande et de Contrôle-Commande), prototype des futures centrales a été développé de manière à évaluer quelle nouvelle organisation permettrait la conduite la plus efficace et sécuritaire ce, en toute situation. Ce prototype sera par ailleurs utilisé pour la formation des opérateurs des futures centrales.

Conclusion

La volonté d'améliorer la sécurité du système existe puisque des efforts sont continuellement mis en oeuvre par les compagnies ferroviaires pour améliorer la fiabilité des équipements. Toutefois, la sécurité du système ne repose pas que sur ce seul élément; elle est déterminée par l'interaction entre les équipements, les procédures et règlements puis les hommes. Pour améliorer cette interaction, les échanges entre la recherche en ergonomie et la R&D de simulateurs apparaissent souhaitables. Les projets auxquels donneraient lieu de telles échanges sont nécessairement des projets de long terme qui doivent être intégrés dans une démarche évolutive. Ils sont néanmoins essentiels si on veut orienter les décisions de court et moyen termes vers un objectif global planifié et cohérent.

Ergonomic Considerations in Arctic Marine Navigation

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Abstract

Based on extensive field research carried out for the Transportation Development Centre, we identify five ergonomics problems in Arctic marine navigation: 1) remote sensing, 2) manoeuvring strategies and ship controllability, 3) bridge design, 4) bridge organization and communications, and 5) design of ports and harbours. We identify three problems: manoeuvring strategies, bridge organization, and design of ports and harbours, as most likely to benefit from the development of an ice-capable marine simulator. We discuss the ergonomic aspects of all of these problems, including remote sensing and bridge design. We list specific research and development breakthroughs which we think are important in each area. We conclude that when economic conditions dictate a return to the Arctic, an ice-capable marine simulator will be a valuable training and research tool.

Résumé

La recherche sur le terrain faite à la demande du Centre de développement des transports a permis aux auteurs d'approfondir les aspects ergonomiques des cinq secteurs suivants : 1) télédétection, 2) stabilité et techniques de pilotage des navires, 3) étude de passerelles de navigation, 4) aménagement des passerelles et communications, et 5) ports. Trois de ces secteurs sont susceptibles de bénéficier plus que les autres de la réalisation d'un simulateur d'opérations maritimes dans les glaces : techniques de pilotage, aménagement des passerelles et ports. Les auteurs abordent tous ces secteurs sous l'angle de leur traitement ergonomique, y compris la télédétection et l'étude des passerelles. Ils mentionnent les avancées technologiques susceptibles d'y être d'un apport important. Ils terminent en disant que lorsque les conditions économiques dans l'Arctique redeviendront favorables, le simulateur d'opérations maritimes dans les glaces se révélera comme un outil d'aide à la formation et à la recherche de la plus grande utilité.

Introduction

The questions to be answered in this paper are: what problems of Arctic marine navigation require human factors input to solve, and can any of these problems be solved with the aid of an Arctic marine simulator? TDC provided us the opportunity to answer these questions seven years ago, when they sent us North to report on both the potential applications for, and the specifications for, an Arctic marine simulator. In this paper, we will discuss the applications. David Ostry of HFN will discuss the specifications in another paper to be presented at this conference.

In 1983, energy prices were up and environmental awareness was down, and it was thought that oil and gas might be moved out of the Arctic in icebreaking tankers. But Arctic gas and oil are expensive, and it still is not clear whether there is enough oil in the Canadian Arctic offshore to make exploitation worthwhile, even if the transportation safety issues are resolved. A recent workshop on Arctic Marine Transportation Research and Development reviewed the state of current Arctic energy transportation projects, which are practically nonexistent (Jarvis & Sutton, 1990). And since that conference, the last major Beaufort Sea player, Gulf, decided to cancel offshore drilling for the 1990 season.

Expectations of immediate development of Arctic energy resources have declined steadily since 1983. Although the current Persian Gulf crisis has increased interest in additional domestic energy resources, many of these resources, like the Alberta oil sands and the Hibernia development, are not on the Arctic offshore. Therefore the economic incentive to develop Arctic marine transportation, and the corresponding incentive to develop an Arctic Marine Simulator as a research and a training tool, disappeared almost as soon as our research was completed. Nevertheless, the question remains: if Canada were to require a larger-scale commitment to Arctic Marine Transportation, of what use would be a ship simulator with Arctic Marine capabilities? And what should those capabilities be?

Our 1983-1986 studies were summarized in three TDC reports: Donderi, D. C. & Ostry, D. J., 1986; Donderi, D. C. & Ostry, D. J., 1985, and Ostry, D. J., Donderi, D. C. & Frenkel, O. J., 1985. In these studies we identified five ergonomic problem areas of Arctic marine navigation: 1) Remote Sensing, 2) Manoeuvring Strategies and Ship Controllability, 3) Bridge Design, 4) Bridge Organization and Communications, and 5), Design of Ports and Harbours (Ostry et al, 1985, pps 28-36.) We will discuss each of these five areas, in turn, in the rest of the paper.

Remote Sensing

Arctic marine navigation requires unique combinations of sensor information, which are needed for three purposes. The first, and conventional, purpose is to establish the ship's position. Gyro compasses and GPS-based positioning systems serve this goal in the Arctic.

The second purpose is to locate dangerous ice hazards at short range. This purpose is served by combining radar and visual observation. Visual observation may be with the unaided eye, which is protected from the intense Arctic glare either by sunglasses or large yellow filter sheets placed over the windows in daylight. Vision may be aided by binoculars day or night, and may be aided by either searchlights or by night vision goggles at night.

The third purpose is to plan a passage to avoid areas of old, thick and therefore hazardous ice. This purpose is served by long-range remote sensing. Satellite-borne synthetic aperture radar will be available on demand in the future. Images from satellite passes will be received and stored aboard ship, where they can be displayed on a video terminal or printed out as a hard copy. Currently, SAR imagery is available from custom-chartered airborne SAR flights, which downlink current, hard-copy SAR imagery directly to image processors and storage devices aboard the ship.

Medium-range passage planning is served by remote sensing vehicles: at present, manned helicopters; in the future, perhaps unmanned reconnaissance drones equipped with video or radar sensors.

HFN was present at the birth of remote radar sensing imagery in the Arctic. During our 1983 and 1984 task analyses aboard M.V. *Arctic* on passages to Nanisivik and to Little Cornwallis Island, Intera Technologies was developing its airborne downlink techniques. The first, and quickly superseded technique was with SLAR (side-looking airborne radar). The second technique, the current technique of choice, is SAR (synthetic aperture radar), which gives a high-resolution, visual-quality image of the ice surface which can be interpreted to identify multiyear floes, ice ridges, and other hazards. HFN suggested the addition of a compass rose and coordinate grids to the raw imagery; a technique which was adopted in Intera's work with hard-copy downlink imagery in the Beaufort Sea.

The interpretation of SAR imagery is an art. The most difficult task is to distinguish between the radar return from first-year ice, which is relatively easy to navigate, and multi-year ice, which is not. The electrical engineering approach to this problem is to modify the properties of the radar to increase the differences in the radar return between the two types of ice. The human factors engineering approach is to discover, through psychometric testing, what features of the existing radar image are used by experts to differentiate between the two kinds of ice. Once these differences have been firmly established, they can be used to design a training curriculum in ice identification from radar returns. A hybrid electrical engineering-human factors approach is to use the information from psychometric studies to develop techniques of image enhancement which emphasize the difference in the existing radar returns between the first-year and the multi-year ice.

Studies of remote sensing are important, but do not require a simulator. The materials can be handled in an ordinary office or laboratory. The technical aspects, use of image enhancement techniques or the preparation of courses and training manuals, do not specifically require a simulator. The problem of interpreting remote sensing information about ice is, however, one of the most important problems in Arctic marine navigation.

Breakthrough. A recognizable breakthrough would be an automatic technique which would reliably put a red ring around every piece of multi-year ice on a SAR hard copy print, or, alternatively, a training or image enhancement technique which would allow a ship's navigating officer to manually do the same thing.

Manoeuvring Strategies and Ship Controllability

Extensive Arctic navigation will require much better understanding of how to control a ship in Arctic ice. The one extant monograph on the subject in English (Parnell, 1986) is a wise compendium of valuable experience, but does not address some issues of potential great importance in the Canadian Arctic.

Cooperative Icebreaking. The normal ice convoy system involves a single icebreaking vessel, with other vessels (possibly ice-strengthened) in convoy behind. Parnell (1986) discusses this situation thoroughly. In the Canadian High Arctic, the situation is somewhat different. The rule in Canadian High Arctic navigation is for the cargo vessel to have substantial icebreaking capacity, and for the escorting vessel (a Coast Guard icebreaker) to be an equally effective, but not necessarily more effective, icebreaker. This raises the empirical question which, to our knowledge, has never been actively studied, of the best means for cooperating between two icebreaking vessels of similar icebreaking capacity but different manoeuvrability.

What seems to be called for is an operations research study, in which fuel budgets, icebreaking work shifts, relative manoeuvrability, and relative ice vulnerability were jointly analyzed to develop icebreaking strategies which led to an optimum solution in terms of minimum passage time or cost, with acceptable risk to both ships. The simulation called for here might be fast-time simulation, where computer models of the process were exercised to determine the optimum solution.

The role of an effective, real-time Arctic marine simulator in cooperative icebreaking is clear. If the simulator could realistically represent the performance of an Arctic icebreaking vessel in mixed first-year and multiyear ice, and if the simulator computing capacity was powerful enough to handle the model of an "other ship" representing the cooperating icebreaker, then the simulator could be used both for training mariners in the cooperative icebreaking manoeuvres, and for studying the best sets of commands, and realistically executable manoeuvres, which could be performed. In other words, the results of an operations research study, which might include fast-time simulation, would be tested on a real-time simulator before being risked in Arctic waters.

Breakthrough. The recognizable breakthrough here would be a manual or monograph on techniques for cooperative icebreaking, which described both the manoeuvres and the command and communications protocols required to carry out the manoeuvres safely and successfully.

Icebreaking Training. Most aviation simulators are training devices which permit inexperienced beginners to practice manoeuvres which might be dangerous to them if practiced in a real airplane. Aviation simulators also permit experienced pilots to practice emergency procedures in response to dangerous conditions that should not be willingly duplicated in flight.

In Ostry et al (1985) we recognized similar uses for a marine simulator with ice modelling capability. A simulator which can simulate ship-ice interactions with first-year ice and with ice ridges and rafting, and which could also simulate the open water caused by icebreaking, could be used as a training device for deck officers involved in conventional ice navigation convoys. The manoeuvres to be practiced would be either breaking first-year ice with an ice-class ship, or following in convoy behind an icebreaker under similar conditions with a conventional ship or an ice-strengthened ship.

A simulator with the capacity to model ship-ice interactions for multiyear ice could be used for training in High Arctic navigation scenarios. In addition to the cooperative icebreaking described above, the routine of single-ship icebreaking under varying ice conditions could be simulated for training purposes.

Deck officers traditionally learn their trade through certification and accumulated experience. But the conjunction of icebreaking with the economics of the Canadian marine situation means that there are few opportunities to gain experience in icebreaking. Watch officers frequently take second place to the experienced ice captain or captains who personally con their ships through dangerous and difficult ice. While this provides opportunities for learning by observation, it limits the opportunities of junior officers to gain "hands on" ice experience. A simulator, where ice manoeuvring could be practiced safely, provides a training alternative to the almost non-existent practical experience offered in the Canadian marine world.

Breakthrough. A recognized breakthrough here would be a capacity to model ice, and ship-ice interactions, on the new wheelhouse simulator being build in St. John's. We identified certain desirable characteristics for a fully capable Arctic marine simulator (Ostry, Donderi and Frenkel, 1985) which are unlikely to be realized in the St. John's simulator, simply because they are too expensive. But a software development program could equip the St. John's simulator to model first-year ice, and to permit the practice of ice-convoying techniques.

Bridge Design

Complex remote sensing instrumentation has been installed aboard the M.V. *Arctic*, at the expense of increasing the depth of the bridge wings to the point where fore-and-aft visibility when manoeuvring during icebreaking or docking is compromised.

This means the captain or watch officer must move from forward to aft in order to maintain visual contact with the ice and water around the ship. This is inefficient. The problem of combining remote sensing instrumentation with conventional navigational instrumentation in a compact, efficient wheelhouse for icebreakers or icebreaking cargo vessels has not yet been addressed.

Bridge design requires drawings, models and mock-ups, rather than dynamic simulation. The design process for bridge design begins with interviews and meetings to determine the ship's mission and its present and projected electronic instrumentation. It then proceeds to concept drawings (using CAD systems for visualization and rapid modification) and from drawings to small-scale models. From small- scale models, the process moves to full-scale static mockups, in which issues of instrument placement and overall design are finally resolved. Construction follows the decisions made at the stage of the full-scale mockup.

Breakthrough. A breakthrough here would be a design contract for the successor to the M.V. *Arctic* which required the bridge design process described above to begin simultaneously with the design of hull and machinery, in close cooperation with the naval architects and marine engineers responsible for the project.

Bridge Organization and Communication

What the aviation industry calls "cockpit management" the marine industry should call "bridge management". As a result of the hierarchical command structures of both airplane and ship, real deficiencies in communication, caused by personality styles and conflicts, have demonstrably led to accidents in which the machinery was not at fault. These are faults which can be mitigated by training, in which protocols for communication are established, and methods of cooperative action, which nevertheless respect the necessary command hierarchy, are taught to both superior and subordinate officers and crew.

An Arctic marine simulator can be used for teaching these communications skills in situations involving manoeuvring in ice, where both inter-ship and intra-ship communications are particularly important. Cooperative manoeuvres with an icebreaker in convoy work, cooperative icebreaking, or docking are situations which demand open and effective channels of communication.

Breakthrough. A breakthrough here would be the use of a simulator equipped to model at least first-year ice, in a training program for bridge crews of ice-strengthened or conventional ships which will travel in convoy with an icebreaker.

Design of Ports and Harbours

The wheelhouse simulator at the U.S. Merchant Marine Academy in Kings Point (CAORF, the computer-aided operations research facility) has been used extensively in planning new fixed installations for marine use. Modifications to the Panama Canal, and to a variety of ports throughout the world, have been simulated at CAORF. The purpose, of course, is to determine whether a simulated ship under human control can be easily and safely piloted in and out of the simulated facility.

The same techniques can be applied to the development of Arctic ports and harbours with an ice-capable wheelhouse simulator. This is particularly important in the Arctic, because the cellular structures used as the basis for several Arctic ports are potentially more dangerous to a ship than the conventional linear surface of a waterfront dock or pier.

Breakthrough. The breakthrough here would be a simulation using both first- and multi-year ice, and including channel effects as well as broken ice, to determine the effectiveness of a proposed Arctic port design.

The Value of Ergonomics

One value of ergonomics in Arctic marine navigation is that better understanding of the interactions between human communications, which is an ergonomics problem, and ship manoeuvrability, which is an engineering problem, make new ideas like cooperative icebreaking possible. By considering the human's capacity to monitor different sources of information, and to resolve and compare visual information from different information sources, old problems, like the integration of information from remote sensors, may find better solutions.

Like other aspects of engineering, ergonomics is a design discipline. The product may be a display system, a communications system, a control system, or some combination. The product may also be a protocol, or procedure, which is taught to system users through a training process.

The efficiency or success criterion for ergonomics applications is often a reduction in accident frequency, a reduction in crew size, a reduction in work-days lost, or, in transportation, a reduction in transit or passage times. When the number of cases in an ergonomics application is too small to permit

quantitative measure, an indirect measure of efficiency like user evaluation on a subjective or objective workload scale may be the only possible measure of efficiency.

In these terms, we are convinced that in any of the areas described here, a skillful application of ergonomics would be rated a success.

The Value of Simulation

It is useless to argue the value of an Arctic marine simulator in the absence of any Arctic marine activity, so the following paragraphs must be treated as hypothetical, until such time as the economic incentive to drive ships North increases again.

Simulators are training tools which cannot endanger the life of the trainees or their crew, and cannot destroy valuable assets as a result of failures during learning. Simulators permit whole-task training, which several studies have shown is very effective in producing maximum transfer to the criterion task. Simulators permit modifications which simplify parts of the task, allowing the trainee's attention to be focused on certain aspects of the task at a time. This has also been found to be a valuable procedure in simulation-based training (Gopher, Weil & Siegel, 1989).

Simulators are research and development tools for new techniques and new equipment. The modifiable environment of a simulator makes it possible to design ports and harbours and test their effectiveness interactively. The visual complexity of a simulator makes it possible to model an environment, like cooperative icebreaking, where there are two or more "active" entities at the same time. This development work can be done in perfect safety, and modifications can be made in perfect safety, before they are tried in the real, and dangerous, environment.

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SESSION 2

Engineering Aspects of Simulators for R&D Applications

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ATELIER 2

Aspects techniques des applications à la R&D

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Aircraft Display Optimisation — A Vision Modelling Approach

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Abstract

A need is identified to produce a computer-based Design Tool to aid the optimisation of psychophysical aspects of visual displays. The production of such a tool should allow the designer to interrogate a visual performance database to obtain the optimal display characteristics for a given application and then to view an emulation of the optimised display. The present paper is concerned with a description of one such tool, that seeks to integrate existing approaches to the problem of display design. As an example of this approach, an algorithm from a model of visual performance is used to predict the conspicuity of coloured symbols on CRTs.

Résumé

Cet article souligne la nécessité de disposer d'un logiciel de conception assistée par ordinateur pour favoriser l'optimalisation des paramètres psychophysiologiques de l'affichage. Un tel outil devrait permettre au concepteur d'interroger une base de données de performances visuelles et d'en extraire les caractéristiques d'affichage optimales pour une application donnée, puis de visualiser une émulation de l'affichage optimalisé. L'article fait la description d'un logiciel de ce genre qui se veut la synthèse des diverses approches actuelles en matière de conception de l'affichage. Témoin de cette démarche intégratrice, l'utilisation d'un algorithme de modélisation des performances visuelles pour prévoir la facilité de perception de signaux couleur sur des terminaux à écran cathodique.

1. Introduction

The aerospace industry employs visual displays in a wide range of applications, including the presentation of conventional flightdeck data, the representation of the outside world (on flight simulators), and even the provision of in-flight entertainment for passengers. Ideally, the process of designing all of these displays to be visually efficient should require engineers to assess the content and layout of information that has to be presented, and then to select the most appropriate type of display technology. In practice, this process is complicated both by extraneous influences on the selection of the type of display (such as size, weight and cost), and by the lack of acceptable quantitative criteria for relating practical visual tasks to the physical characteristics of displays. The latter feature is commonly exemplified by the need for iterative refinements of display prototypes, to overcome significant initial over- design. Such trial and error methods are obviously time consuming and therefore costly. In order to assist the designer to better understand the limitations of visual performance in relation to specific display technologies, a collaborative research programme commenced in 1989 under the EEC ESPRIT initiative, with the aim of constructing a computerised Design Tool. The primary aim of the present paper is to outline the basic functions of this tool, as a means of describing ou general approach to the display design process.

The rudiments of such an "expert system" for display design have been available for many years. Dedicated CAD packages such as TIGERS (CAE Electronics Ltd.) allow the designer to produce rapid prototypes of specific formats without recourse to building hardware. Such packages rely on the user's own knowledge, which itself frequently reflects rules-of-thumb suggested by existing manuals for display design (e.g. Krebs et al., 1978). Secondly, a number of laboratories throughout the world have extensive research experience of the general visual problems facing pilots (such as changes in chromatic adaptation with changes of line of sight) and of performance on specific visual tasks -- for example the formatting of information about the stores being carried by an aircraft (Aretz and Calhoun, 1982). Thirdly, there exist a growing number of useful quantitative models for predicting visual performance, based on fundamental vision research. For example Carter (1989) shows how a simple modification of an existing colour-difference equation can be used to calculate the effect of symbol size on operator performance. Finally, there exist dedicated emulation facilities that allow the user to see what a design would look like on a specific

type of display. For example, one European research group has developed a facility for emulating flat panel displays on a CRT (Meulen, A.E., 1987).

The present research programme seeks to provide an integrated tool that contains all of the elements outlined above. The ultimate goal is to provide the designer with a user-friendly tool that will operate on a desktop workstation.

2. Design Tool Description

2.1 Scope

It is important from the outset to clarify the nature of the tool under development. We have attempted to focus our research on psychophysical aspects of displays, by which we mean the impact of simple features of the display, such as resolution, colour, and refresh rate on visual performance. Higher-level cognitive features are not considered. In the future, it is intended that the tool will be used in conjunction with cognitively oriented models. In addition, it should be emphasized that many of the basic psychophysical data are to be generated within the project, so that there will be an opportunity to redirect elements of the experimental work in line with designers' comments.

2.2 Design Tool Environment

An overview of the Design Tool is given in Figure 1. The existing software has been developed under UNIX on a SUN Microsystems 386/250 computer. The user is provided with an Openwindows and HyperNeWS/GoodNeWS interface, a fourth generation database, and a CAD drawing package. On-line help is also given. This serves the dual role of route finding around the software and offering alternative sources for information not contained within the tool.

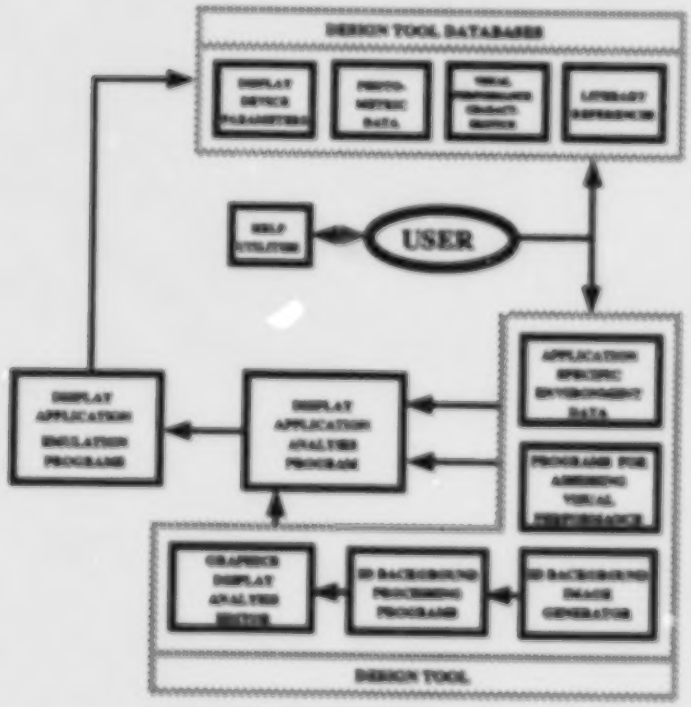

Figure 1: Summary of the Design Tool Structure

2.3 Design Tool Databases

Four database components are accessible to the user. The display device module comprises information (both graphical and textual) on the display size, type (e.g., CRT or liquid crystal), spatial resolution (e.g., dot pitch and pixel geometry), luminance and colour (e.g., number of grey levels and phosphor types) and temporal resolution (e.g., scan rate and phosphor decay time). These data are taken either from manufacturers' specifications or from in-house measurements.

The photometry module contains raw spectral data on the colorimetric properties of individual filters, illuminants and phosphors and allows the user to calculate and display their combined values.

The database on visual performance is perhaps the most important element of the tool. We describe performance under the three major headings of colour, motion and image quality, although obviously the three are interdependent. The database contains a wide variety of information, including empirical data for specific viewing conditions, and vision models and equations for predicting performance where no data exist. There are two main components of the colour module. First, there are data and equations for threshold colour discrimination, with particular reference to the issue of small symbols typical of modern aircraft displays. Second, we are establishing a conspicuity database, which includes a facility to determine the maximum discriminability for a number of colours specified by the designer. In addition, the tool should establish the maximum number of colours that can be used simultaneously to prioritise information (i.e., such that the relative conspicuity between colours could retain a meaningful rank ordering).

The motion perception module is primarily concerned with establishing the most economical set of parameters which the visual system will interpret as continuous movement, and is based on existing physiological models of motion perception. The development of this research is complex, because the relationship between the physical display parameters and movement information depends on object speed, contrast and spatial frequency content, eccentricity of viewing and mean luminance level. It is intended that the designer will be able to view static emulations of motion effects resulting from specific combinations of target/display parameters, for example the smearing effects that result from the slow response of liquid crystal devices.

The image quality module contains general guidelines for the use of fonts given fixed (e.g., pixel size and shape) and variable features of displays (e.g., requirements for upper/lower case). The data set will also include recommendations for some specific situations – such as pixel arrangement for liquid crystal displays. Provision is also made for the inclusion of data on the type of scaling and the number of grey levels needed to yield a perceptually linear grey scale.

The bibliography module contains a readily accessible index of relevant literature, including general sources of display guidelines and scientific papers on specific topics for users who wish to pursue issues in more detail.

2.4 Design Tool Subroutines

Some users might only wish to interrogate the database outlined above. Most designers, however, would appreciate the utility of being able to view and assess an emulation of the recommended design. To help achieve this, several facilities are included. First, the user must provide the tool with information about the display environment (e.g., its size, the ambient illumination and viewing distance) and about the information to be displayed (e.g., the number of application parameters needed). Optionally, application specific background images can then also be entered and stored, via commercially available line scanners or video frame grabbers. The image can then be manipulated, using techniques such as spatial filtering, contrast enhancement and compression, noise reduction and space-averaged luminance selection. Other features of the design can be entered with the graphics editor, which provides the user with drawing facilities (such as lines, arcs and text). The resulting drawing can then be superimposed on the previously stored background images. The display application analysis program requires that the user has allocated levels of a number of variables to each drawn entity (for example, the priority associated with it). The program can then display, among other things, a colour-luminance combination for that entity. The user can also view an emulation of the display. Some problems will occur at this point, because some display devices will not support the range of colour-luminance values selected. In these cases the nearest available values will be displayed, but a separate data file is created indicating the approximations involved. Finally, the program contains a visual assessment module, which provides functions to measure visual acuity and colour discrimination. This could be used to document the visual characteristics of anyone evaluating the emulated display design.

3. Prediction of Symbol Conspicuity

Clearly, it is important to validate elements of the Design Tool. To illustrate the type of visual performance algorithms that must be developed, we describe an experimental study of the accuracy of the British Aerospace vision model to predict symbol conspicuity. The model (code named ORACLE) has been developed over the past 20 years to predict threshold visual performance, based on the known physiology and anatomy of the visual system. It has been extensively calibrated in laboratory and applied settings (Overington, 1976). Nonetheless it is to be emphasized that the model is only one of several currently available, and we do not imply that this model would be included in the final version of the Design Tool. Such algorithms can yield rich rewards to the designer, relative to the quantity of input data needed (in the present case the spectra of the target and background, target size, ambient illumination and display MTF). This is particularly evident when the algorithms are used to predict visual performance on displays that have not been empirically tested. The experiments are more fully described elsewhere (Johnson, 1990). In brief, they were concerned with the scaling of the threshold version of the model (which yields predictions of the contrast required to achieve a 50% probability of detection) to suprathreshold conditions. Ranking judgements were obtained from 5 subjects of the relative conspicuity of rectangles of various dimensions (areas between 16 mrad^2 and 160 mrad^2), presented for 0.33 sec, under ambient illumination of 5000 Lux. Figure 2 shows the Measured Conspicuity (an empirical measure of the conspicuity of each condition with respect to all of the others at that level of illumination) plotted against visibility predicted by ORACLE, for four shapes, each at several levels of luminance contrast. The "Oracle Visibility" term is calculated from ap, the number of standard deviations above the mean threshold contrast, and sigma, the standard deviation relative to that mean. It is clear that under these experimental conditions, the linearity of the relationship between predicted and obtained symbol conspicuity suggests that the designer might have a reasonable degree of confidence about using the algorithm predictively. By linking the inputs and outputs of such a vision model to the Graphics Editor, one obtains most of the basic information to allow the Display Application Analysis program to produce some initial recommendations that could be output to the Display Emulator. At this point one reaches the next stage of the design process, where the Human Factors engineer must address the problem of evaluating the end user's performance with the "optimised" display.

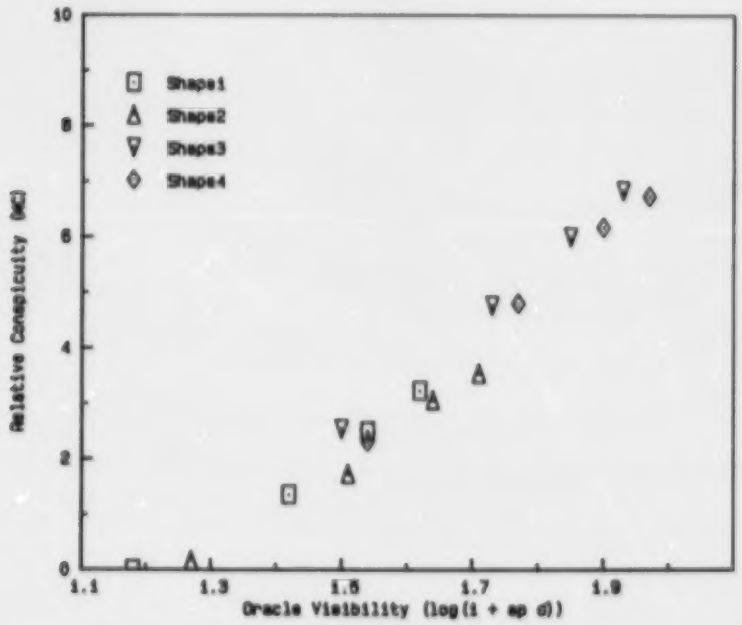

Figure 2: Predicted vs measured conspicuity of coloured symbols

4. Conclusions

The technical specifications of visual displays suitable for use inside and outside the cockpit are changing rapidly. In addition, the amount and type of information that must be displayed varies considerably. It is suggested that in selecting between competing displays, the design engineer must carefully assess the visual performance of the end user. Given the large and sometimes conflicting literature on visual performance with displays, it is hoped that the type of Design Tool described in the present paper can be used to improve the consistency of this selection process.

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Driving Simulators and Automotive Engineering

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Abstract

This paper presents an overview of our current thoughts regarding driving simulation at the General Motors Systems Engineering Center. It provides a list of converging factors and trends which favor including driving simulators as part of the set of engineering tools used in automotive engineering. The paper includes a comparison of the strengths and weaknesses driving simulators have with respect to another tool used for vehicle technology development — the variable response car. An attempt is made to list key simulator subsystem characteristics as they pertain to emerging vehicle technologies which may affect the driver's navigation, guidance, and control tasks. The paper suggests a limiting boundary for the driving simulator application domain in the vehicle design process and concludes by proposing a phased procurement approach as an effective alternative to purchasing a multimillion dollar facility all at one time.

Résumé

Cet article donne un aperçu des questions sur lesquelles se penche actuellement le Centre d'ingénierie des systèmes de General Motors en simulation de conduite automobile. Il énumère les facteurs et les tendances qui favorisent l'inclusion de simulateurs de conduite dans la panoplie des outils mis à la disposition des concepteurs automobiles. Il fait notamment l'inventaire des forces et des faiblesses du simulateur de conduite par rapport à un autre outil utilisé dans les travaux de développement en technologie automobile, soit la « voiture à comportement variable ». Il énumère les principales caractéristiques des sous-systèmes de simulation qu'il faudra peut-être réétudier pour prendre en compte l'influence des technologies émergentes : guidage routier embarqué, visualisation tête haute, etc., sur la tâche du conducteur. L'article suggère de limiter le champ d'application des simulateurs de conduite dans la conception de véhicules et conclut en proposant, pour l'achat de simulateurs, une démarche graduelle, plutôt que d'investir d'un seul coup les millions de dollars que coûtent ces installations.

Introduction

Definition and Description

For the purpose of this report, a driving simulator can be defined as a dynamic electro-mechanical system that interacts with a human operator in real time to imitate some aspects of the appearance and functions of an existing, proposed or purely imaginary automobile. A general block diagram for a driving simulator is shown in Figure 1. Ideally, the simulator is under the control of a host computer which directs the scenario or sequence of events presented to the driver. Simple simulator facilities rely on the experimenter to control the event sequence or to initiate the sequences which are under microprocessor control. Driver control inputs (steering, brakes, throttle) from the instrumented driver compartment are processed by vehicle equations of motion to yield inputs to the vehicle motion system, instrument panel displays (speedometer, tachometer), sound system (engine and road noise, tire noise, wind noise, etc.) and other subsidiary displays (e.g., rearview mirror scenes). Simple performance measures (e.g., lane deviations, steering reversals, average heart rate, etc.) are typically calculated on-line and displayed after each run. Results are also stored, along with the raw data, for later statistical analysis (e.g., analysis of variance, correlations, etc.) and for future in-depth data reduction and analysis.

Reasons for the Current Interest

Considerable research on driver-vehicle performance either performed directly by or sponsored by GM has involved the use of driving simulators (1-4). GM has built three research simulators of its own as well as funded the development or upgrading of several university facilities (5-7). The current interest in driving simulators at General Motors is the result of a variety of converging factors and trends. No particular ranking is assumed in the list that follows.

- Development engineers are very adept at setting goals for new vehicles that are roughly similar to those currently produced, but this task could become very difficult if considerably different vehicles are required in the future. A driving

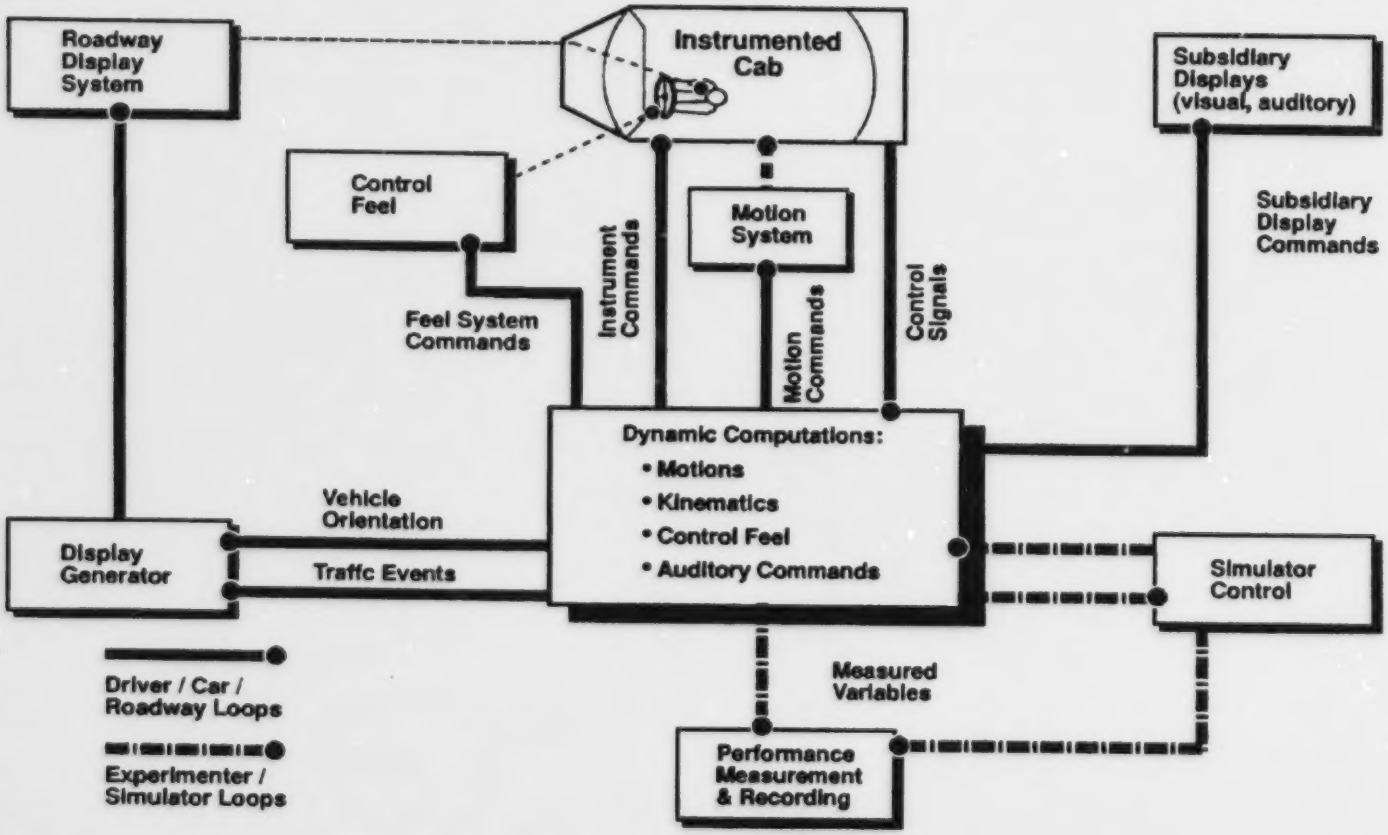

Figure 1: Typical Driving Simulator Elements (Ref. 18)

simulator would be very useful in checking these goals against product expectations early in the engineering process.

- There is a growing appreciation of the need to consider a wider range of alternative vehicle concepts before committing to preliminary and detailed design of a particular concept. A simulator would provide a means of experiencing first-hand some of the key differences in the concepts.

- Simulators can be viewed as an extension of computer aided engineering and design. Models for subsystems or components can be integrated into the real time simulator process and "driven" under simulated operating conditions.

- While it may be possible to define and model the subsystems and component parts of an automobile, the synthesis of these subsystems into the complete vehicle is becoming so complex that a judgment on the performance of the whole may not be possible from theoretical models alone; it may require physical simulation.

- The driver's compartment is becoming increasingly complex, and there is a need to establish requirements for the proper utilization of new displays and controls under controlled laboratory conditions that are at the same time representative of a person's information processing load while driving.

- There is a need to get the reactions of typical drivers and customers to advanced vehicle concepts early in the engineering process before working hardware is available and when design changes are easy to implement.

- Computer generated image techniques have made significant strides in recent years so that it is now possible to create quite realistic roadway scenes in near real time.

- Realistic laboratory driving simulators can now be built at a cost comparable to that of an over-the-road simulator or variable response vehicle.

Pros and Cons

Ideally, a driving simulator is one element of an overall program which includes modeling, simulation and vehicle test work, and which combines the strengths of each approach to investigate vehicle design issues in which the driver and his reactions play a central part. An integrated approach would utilize driver-vehicle models to support the setup, data reduction and analysis of combined simulator and vehicle experiments. Ultimate realism would be obtained by observing drivers operate instrumented vehicles on the open highway.

Whether or not a comprehensive approach is taken, the strengths and weaknesses of simulators relative to vehicle test methods must be considered. Vehicle test work will always be a part of any vehicle program. The question is, do simulators offer enough advantages to justify their inclusion as well? The type of test vehicle that comes closest to the intent of a driving simulator is one in which ride, handling and/or steering characteristics can be quickly varied for back-to-back comparisons under nearly identical conditions. General Motors has had several such vehicles in the past (8,9) and since this type of "over-the-road simulator" is accepted as a useful tool, it provides a reference for judging the strengths and weaknesses of laboratory simulators.

Some important evaluation criteria for judging the strengths and weaknesses of driving simulators are summarized in Table 1. Many of the comments in this section are based on the material in Reference 18. The fidelity criterion relates to the subjective realism of the testing situation. A "high fidelity" test environment gives a strong feeling of the real driving task and causes the driver to respond as he would in the real world. A real car driving in real world traffic conditions provides the ultimate fidelity. Simulators can be graded on characteristics such as the visual scene, auditory cues, control force feel, and motion cues. It is clear that in a simulator some cues are always lacking or distorted and that it is difficult to motivate the subjects the same way as in actual driving. Variable characteristic vehicles also introduce some form of distortion in their sound, control feel, and/or ride characteristics. The various pieces of test course apparatus lack fidelity relative to driving on public roads in real traffic conditions. New developments in computer generated graphics technology will soon allow presentation of more realistic emergency situations than can be achieved on a closed test course. In general, ho-vever, the fidelity of a laboratory simulator is considerably less than a variable characteristic vehicle.

Validity is concerned with the correctness of the objective engineering measurements of the closed-loop driver-vehicle system response. Simulators clearly use simplified models of the vehicle and the environment, and the combined driver-vehicle system response in a simulator must always be viewed with caution when extrapolating to real driving. While results of studies with test vehicles

Table 1
Simulator/variable response vehicle tradeoffs

Factor	Simulator	Variable Response Vehicle
Fidelity	• Some cues lacking or distorted • Realistic motivation difficult	• Visual and motion cues are free
Validity	• Simplified vehicle and environmental models • Always questionable	• More readily accepted
Control	• Excellent	• Difficult to control all variables
Flexibility	• Easy to manipulate over a wide range	• More limited range
Measurement	• Variables readily available	• Requires sensors and conditioning
Logistics	• Convenient	• Related to driving scenario complexity and environmental constraints
Safety	• Some concern with motion and control feel systems	• Extreme maneuvers can be a problem
Maintenance	• May be problem with high complexity	• More environmental exposure problems
Cost	• High fidelity very expensive	• High fidelity expensive • Scenario complexity can be costly

are more readily accepted as valid, the very fact that the driver is taking part in an experiment and the existence of instrumentation on the vehicle and, in some cases, on the driver himself will influence the results.

The control issue has to do with the degree to which experimental conditions (independent variables) can be controlled and manipulated without the presence of other uncontrolled or confounded variables. A simulator can provide a range of vehicle dynamics, visibility conditions, aerodynamic disturbances, etc., which can be readily varied or precisely repeated from one run to the next. These types of variations or repeat conditions are very difficult if not impossible in the field. Ideally, one can recreate at any given time whatever environmental situation is of interest in a simulator. This is obviously not the case for field tests.

Flexibility is concerned with the range over which the experimental conditions can be varied. A simulator can represent vehicle configurations that do not yet exist in operational hardware. If a concept exists in the form of an equation or a computer simulation, providing that it can be executed in real time, it can be represented on a driving simulator. Variable response vehicles, on the other hand, have fairly limited operating ranges.

On the issue of measurement and analysis, computer controlled simulations directly generate the vehicle and situation variables that are of interest and often in a format that is directly compatible with subsequent

data processing. Under field conditions, sensors must be provided for various experimental variables. Additional onboard or offboard processing of sensor data may also be required in order to obtain the desired variables.

Experimental logistics have to do with the effort required for the preparation and execution of an experiment. A human use committee must approve the experimental protocol if outside subjects are used, safety factors may dictate additional support personnel and facilities (e.g., emergency medical equipment), field test scenarios will require support vehicles and operation of test course devices and instrumentation, and it will be necessary to schedule access to essential facilities (such as test tracks). It is clear that a driving simulator facility offers much more convenience compared with field testing in each of these areas.

Safety considerations clearly favor the use of laboratory simulators. Motion base systems and force feel systems can introduce some risk, but in general, simulators present an inherently safe environment for driving research. This is especially important under conditions that involve exposure to accident situations which cannot be reproduced ethically under real-world conditions. Investigations that involve impaired drivers or seriously degraded vehicle or environmental conditions also fall in this category. Some advanced vehicle concepts will have their greatest impact in emergency situations, and the failure of some advanced systems may also create new problems for the driver. Intrinsic driver-vehicle performance limits are usually best measured under high task-induced stress conditions which can be more readily and safely achieved in a laboratory simulator.

Maintenance can be an issue both for simulators and experimental vehicles. As the complexity of a simulator increases, particularly in the areas of computer generated image systems and multi-degree-of-freedom motion platforms, routine maintenance requirements will increase. In general, however, the increased exposure to environmental elements creates greater maintenance problems for operating test vehicles.

The cost issue includes development, setup, routine maintenance and facility staffing. While the cost of a high fidelity driving simulator can exceed several million dollars, this is comparable to the cost of a highly flexible variable characteristic vehicle. Even without variable response capability, complete instrumentation and recording systems for in-vehicle tests can be expensive to set up and maintain. Also, the instrumentation must be installed in every test vehicle vs. once in a simulator. Contriving typical traffic situations, including interactive vehicles and traffic signals on special test courses, can be costly.

To sum up, the primary advantages of a simulator approach are in experimental control, flexibility, measurement ease, convenience, safety and maintenance.

Driving Simulator Subsystem Considerations

Nature of the Driving Task

An attempt has been made to identify driving simulator subsystem characteristics needed to study the various types of driving tasks which will be affected by different types of advanced vehicle concepts.

A useful top level view of the driving task separates it into three major functions; namely, navigation, guidance and control. Navigation involves route finding and following assisted by maps, highway and street signs, and various landmarks and way points. In-car navigational aids of various types are being given serious consideration as a means of assisting the driver with this function. The need to navigate can create extra workload and potential confusion for the unfamiliar driver, distracting him from other aspects of the driving task, including the need to monitor for potentially hazardous situations.

Guidance involves directing the vehicle along a delineated and/or designated pathway and requires the driver to perceive the appropriate cues such as turnoffs and other vehicles in order to select the appropriate path and vehicle speed. Here again, advanced vehicle concepts such as collision warning systems and proximity detectors have been proposed to assist the driver with this function.

Utilizing the appropriate guidance cues, the driver must then perform the necessary control function via steering, throttle and brake commands in order to maintain directional stability, regulate against aerodynamic and road disturbances, follow the selected pathway, avoid roadway obstacles and maintain the proper following distance. Here too, a variety of vehicle factors may influence the driver's performance of this function, such as steering properties that provide improved road feel, active suspension systems that filter out road disturbances, and handling qualities that improve directional stability and control response.

The three categories of driving tasks can be thought of as being part of an overall hierarchical multilevel structure of vehicle control. The navigation loop

Table 2

Driving Simulator Subsystem Requirements as a Function of the Driving Task

	DRIVING SIMULATOR SUBSYSTEM REQUIREMENTS						
DRIVING TASKS	**VEHICLE DYNAMICS MODEL**	**ROADWAY DISPLAY**	**MOTION SYSTEM**	**DRIVER CONTROLS**	**SOUND**	**INSTRUMENT PANEL**	**NEW VEHICLE SYSTEMS**
CONTROL • Speed Control • Lateral Control • Skid Control • Obstacle Avoidance Time Frame: Seconds or Less	• Nonlinear • Individual Tire Representations	• Dynamic Realism • Speed Cues • Variable Weather and Road Conditions • Day/Night	• Angular & Translational • Vibration • Onset & Sustained	• Highly Realistic Steering Wheel & Brake Pedal Feel • Reconfigurable	• Tire/Road Noise • Engine/ Exhaust Noise • Wind Noise	• Reconfigurable	• Drive by Wire • 4 Wheel Steer • Active Suspension • Mode Failure Warning • Impairment Detection • Anti-Skid/Lock • Collision Warning • Road Surface Monitor
GUIDANCE • Lane Selection • Car Following • Obstacle Detection • Interacting with Traffic Control Devices Time Frame: Seconds	• Linear	• Other Vehicles • Traffic Control Devices • Day/Night • Variable Weather and Road Conditions	• Onset Cues • Vibration	• Moderately Realistic	• Traffic Sounds • Road/Tire Sounds	• Reconfigurable	• Collision Warning • Proximity Detector • Night Vision
NAVIGATION • Route Selection • Route Following Time Frame: Seconds to Minutes	• Linear	• Road Signs • Landmarks • Traffic & Traffic Devices • Day/Night	• Onset Cues • Vibration	• Rudimentary	• Rudimentary	• Reconfigurable	• Navigational Aids • Cellular Phones

forms the highest level in the control hierarchy. The time frame for navigation is on the order of several seconds to minutes or longer. The outputs of the navigation loop are the inputs to the guidance loop, whose outputs, in turn, represent the inputs to the innermost control loop. The control loop operates at higher frequencies than either of the two outer loops. The guidance loop operates in a time frame of seconds, while the control loop operates in a time frame of seconds or less. These time frames must be kept in mind when considering the simulator design requirements in order to do an adequate job of representing the driving task of interest.

Table 2 provides a description of the driving simulator subsystem characteristics needed to study each of the three main driving task functions. The control function places demands on the dynamic realism of the roadway display, the control feel of the steering and braking control devices, the fidelity of the vehicle equations of motion and the realism of the motion and auditory cues. The guidance and navigation functions place greater demands on the roadway display system but still require realistic simulator handling characteristics to avoid unnecessary increases in driver workload. Some considerations for the different simulator subsystems are discussed in the following subsections.

Visual Display Subsystem

The simulator visual display subsystem plays the single most important role in giving the driver the illusion of actually driving a car. This includes control-related information, like lateral position, heading angle and road coefficient of friction; guidance information, like road geometry and the presence of other vehicles; and navigational information, like highway signs and landmarks.

Functional requirements for the visual display fall in the categories of size, distance, resolution, color and distortion. These are shown in Table 2 as a function of the three driving tasks categories. It is not possible, based on existing scientific knowledge, to completely specify those features of the visual scene that a driver uses for each and every driving task or maneuver. The following discussion is therefore based, in part, on the limited knowledge that does exist and, in part, on the authors' experience and judgment. Most of the visual information used by the driver in guiding the vehicle, that is the preview of the road ahead, is contained within a 20° cone (10,11). This suggests that a relatively small display in terms of lateral visual arc might be sufficient for control tasks. On the other hand, visually induced sensations of motion are most readily achieved, at least for aircraft simulators, when the field of view is larger than 60° and ideally when it is a full 180° (12). The motion in the central field appears to be relatively unimportant in generating motion sensations.

A wide field of view is certainly more realistic and is clearly desirable for such guidance related tasks as urban maneuvering. Indeed, one could argue for the presence of 360° of visual field in order to allow the type of visual scanning behavior that normally accompanies this type of driving. Navigation behavior probably requires a field of view more in the neighborhood of 120°-180°. A somewhat ironic point in all of this is that although a wide field of view enhances the realism of the situation, it is also known to increase the likelihood of subject uneasiness, especially if there are no physical motion cues presented. The explanation for the phenomenon of simulator sickness is related to the cue conflict that arises when there are strong visually induced sensations of motion but no actual physical motion or physical motion which is discrepant with visually induced sensations (13-15).

On the issue of display distance to the driver, it must be remembered that the real world visual scene is tens to hundreds of feet in front of the driver. At the same time, simulator screens need to be kept close to the driver compartment to minimize their size and space requirements, especially if they are mounted on a motion platform. To provide a more distant focus and accommodation angle of the eyes, a virtual image can be generated by a collimating lens placed near the driver's eyes (7,16,17) or by a large spherical mirror reflecting the source image. The distant-focus feature is important in instrument panel display and control studies where the eye must change accommodation between instrument panel viewing (about 2.5 feet) and roadway viewing (about 25 feet to several hundred feet).

The resolution of the visual scene does not appear critical for steering control tasks. The driver is believed to control the path of the car through combined perception of heading angle and lateral position relative to the roadway and local curvature of the roadway (18). Even under somewhat degraded viewing conditions, these delineation cues are usually adequately perceived (10). The presence of texture in the roadway scene can enhance the illusion of longitudinal motion. For guidance and navigation tasks, high resolution is required in order to read traffic signs, detect obstacles, etc.

With regard to color, it certainly appears true that color scenes are more realistic than black and white versions. However, for control tasks, a black and

white display would probably provide sufficient information as long as some means of denoting change in road surface condition (e.g., ice or snow) were possible. For guidance and navigation tasks, important information is encoded in color, such as traffic lights, brake lights, types of roadway signs, etc.) so color would be essential. Flight simulator experience also indicates that pilots judge a color display image to have higher resolution than black and white and that object detection and recognition is improved (20).

Some image distortion can probably be tolerated if it is not of a dynamic nature nor severe. For control type tasks, time delays must be kept to a minimum to avoid the feeling of driving a sluggish vehicle (7) as well as distortions in driver performance. Time delays have also been identified as one cause of simulator uneasiness (13). For guidance and navigation tasks, longer time delays can probably be tolerated. Since an image streaming across the retinal field is believed to provide an important cue for the driver's control of the vehicle's path (10), it is important to ensure that display motion is smooth in nature. Lack of display smoothness can also be the cause of subject discomfort (7,13).

There is little doubt that the source of visual image generation information will in the future reside in computer systems (12). The factors characterizing the visual system are therefore not mutually exclusive. For one channel of display and a given bandwidth, for example, field of view and resolution are inversely related. Scene detail and computational delays are also inversely related. In addition to interactions between visual system characteristics, there is a powerful interaction between visual and motion cues. A large field of view can compensate to some degree for limitations in, or absence of, a motion system in those cases where lead cues are needed for proper vehicle control (12). The next section deals with the motion system in more detail.

Motion Subsystem

In general, we do not know how much motion is required for different driving tasks. The answer requires precise identification of which characteristics of the motion input the driver responds to and of the effects of false inputs on his response. Poor motion can be worse than no motion. Figure 2 shows an attempt to display all of the possible ride and handling motion, vibration and sound requirements of a simulator in terms of the range of maximum strokes required to achieve them over the band of frequencies involved (21). The large range of motions and frequencies precludes the use of any one physical mechanism to produce them. As a result, the requirements have been broken down into smaller groups as shown in Table 3, each of which should be achievable to some extent by the appropriate mechanism indicated. The audio effects will be discussed in a later section.

A good motion system greatly enhances the impression of realism in a simulator. It is most important to have motion for control tasks where the motion provides information concerning the effects of various driver control inputs and serves to influence the manner in which the driver manipulates his controls. Abrupt, almost step-like inputs into the controls are frequently observed in fixed base simulators (5). They are not used when motion is present because the driver is immediately chastened via simulator movements for other than smooth, continuous control manipulations. The presence of motion in wind gust regulation tasks results in earlier recognition and reaction to the gusts (5,21).

Another reason for including motion cues for control task applications is the degradation in performance that may occur due to motion. This could be particularly important in the study of unconventional steering system technologies like joysticks where the presence of vibration and motion may affect the driver's ability to provide precise control inputs. Motion information is also important where an unstable or near neutrally stable vehicle has to be controlled (e.g., when the rear wheels lock up).

Even in the case of studies directed at instrument panel displays, motion can be important because it serves as a powerful alerting input, directing attention to or producing an instinctive reaction to a vehicle's response, even though it was not the center of the driver's attention at that time. For example, if a driver inadvertently turns the steering wheel while looking away from the road to adjust the radio, he is immediately made aware of the change in the vehicle's direction from the motion cues.

During 1985, several simulator facilities were visited by the authors. The motion system approach that provided the most realistic cues for a lane change maneuver was the one used at the VTI Swedish Road and Traffic Research Institute (22,23), which provided ± 3 m of lateral excursion. There appears to be no substitute for pure lateral motion to simulate transient lateral accelerations. It was the authors' impression, however, that a spinout was simulated more realistically on the system used by Daimler-Benz (27) where a relatively large range of yaw motion ($\pm 57°$) was available.

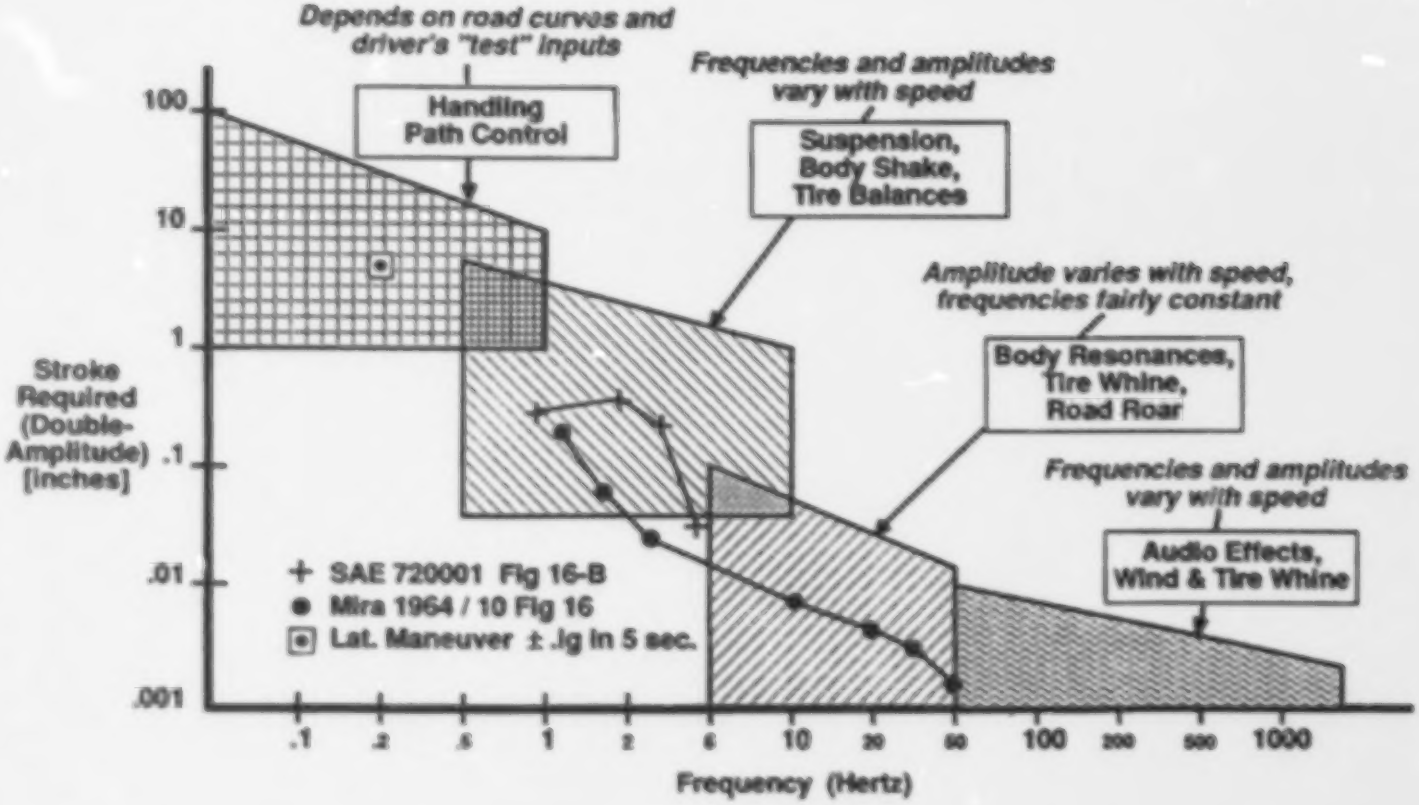

Figure 2: Driving Simulator Motion, Vibration & Sound Requirements (Ref 19)

Table 3
Simulator motion requirements
(Ref 19)

Type of Motions	Frequency Range (Hz)	Stroke or Pressure Required	Appropriate Mechanisms
Handling	.1-1.0	1-10 in.	Tilt, via hydraulic actuators or electric screw jack servos
Ride: road, suspension, and shake	.5-10*	.05-5.0 in.	Hydraulic servos -- high bandwidth (0-30 Hz)
Body, tire, resonances and road roar	5.0-100	.002-.10 in.	Electrodynamic seismic shakers on cab
Audio effects (wind noise, engine, tire whine, etc.)	50-1000	< 90 pn dB in cab	Hi-fi speaker system

A common source of complaints in a motion system is lack of smoothness in its movements (24). This is because people are very sensitive to discontinuities or "jerk." One way to mask a lack of smoothness as well as to provide an added degree of realism in its own right is to introduce small random vertical motions. The VTI simulator in Sweden has an inner vibration platform for this purpose that is quite realistic. It has been observed in helicopter simulations that the addition of physical vibrations uncorrelated with movement observable in the visual display is much more realistic than the same simulation without the physical vibration (25).

Host Computer

The host computer initializes and coordinates the activities of the various simulator subsystems. Basically, it samples the driver's steering, braking, and accelerator inputs, solves the vehicle dynamics equations, and transfers relevant parts of the solution to each subsystem. The time it takes to complete this cycle defines the simulation's frame time. The major requirement on the host system is that it have enough computational and data acquisition (I/O) speed to accomplish the cycle for real time operation (26). There are certain computational and I/O issues which have a bearing on selecting a host system and its architecture.

The computational demand on the host processor is predicated by the integration steps performed in solving the vehicle model. The vehicle model consists of the equations of motion given as a function of the external forces (and moments) acting on the vehicle. These forces are the aerodynamic and tire forces (translated to the vehicle coordinate system). The tire forces and moments are those incurred while turning, braking and accelerating and are related to the longitudinal and lateral tire slip angles, tire dynamics and carcass elasticity. They are also affected by vertical loading and suspension configuration and compliance. The complete vehicle model also includes models for engine, transmission, and pedal and steering position transfer functions.

The host computer architecture also depends on how the model and associated software is partitioned. One approach is to partition the solution by utilizing multiple processors to solve for the forces at each tire concurrently. Other tasks such as modeling the engine and transmission, interfacing with the operator console and data acquisition would be handled in still another processor.

Another factor in host system selection is I/O capability. The I/O requirements are time critical because of the large number of channels involved, which depends on the extent of the simulation but can easily exceed 20 channels. Inputs include driver accel-

erator, steering, and braking commands along with subsystem status communication and operator console inputs. Outputs are vehicle position, velocity and acceleration data for the visual and motion subsystems, sound frequency and amplitude data, status information to the operator's console, and driver information systems such as speedometer and tachometer. Software to accomplish the I/O cannot be written in the customary high level languages but requires custom I/O routines in assembler using the host's operating system capabilities.

Another important issue in host selection is the availability of good programming tools. The largest cost in any modern simulator development is software. The host should have proper tools such as a user friendly editor, powerful macro command file capability, and good operating system documentation. Power and environmental requirements should also be considered along with the manufacturer's software and hardware service track record.

Control Feel Subsystem

Control feel characteristics vary greatly among cars and significantly contribute to the subjective differences among them, especially between family sedans and sports cars. Most of the more recently developed driving simulators have provision for variable feel to the steering wheel to simulate friction, centering forces and road feel effects. Based on observations from several decades of experience with research-oriented flight simulators, the simulator pilot has been found to be much more critical of non-linear aberrations (friction, deadbands, "slop," poor centering) in his primary maneuvering controllers in the simulator than in the actual aircraft (12). In fact, it might be generally stated that specifications on control feel characteristics should be more demanding in the simulator than in the aircraft. The apparent reason for this is that in the cue deprived environment of the simulator, erratic nonlinear controller dynamics become much more noticeable and add to the already increased workload due to the absence of the full range of sensory cues (12).

Auditory Subsystem

The purpose of an auditory system is threefold; first, to provide realism; second, to provide potentially important driving cues; and third, to mask unwanted sounds. There is no particular difficulty in providing a whole range of sounds. Identifying which are important and acquiring the data for their proper representation is more of a challenge. A high fidelity sound system properly coupled to the driver compartment can even provide some degree of road feel. Human factors studies indicate that subjects give vehicle ride quality a lower rating if the noise level is high.

In most of the currently operational driving simulators, proper representation of the subtle sound differences between car models is not modeled. The Daimler-Benz simulator is one exception. In fact, because they attempt to represent the true sounds of their vehicles in their simulator, the actual sound levels present are often quite low. The authors had an opportunity to drive an actual vehicle prior to experiencing it in the simulator, and can attest to the fact that the sound simulation was quite realistic. Others who had not driven the actual vehicle felt that the sound system in the simulator was lacking in realism and amplitude. This points out an interesting point about simulators; namely, in order to achieve high perceptual fidelity, it is sometimes necessary to sacrifice objective fidelity to some degree and intentionally distort some of the sensory cues.

Driver's Compartment

The driver's compartment provides a place for the subject to sit, view the visual roadway and sign displays, and interact with vehicle controls and information systems. The design of the compartment is a tradeoff between good face validity, low-cost fabrication, and rapid reconfigurability. On the one hand, an actual production vehicle with production controls and displays would provide the most face validity. On the other hand, the investigator's interest in changing the car's controls and displays might suggest a special mockup or "buck" with a readily reconfigurable interior. An array of instrument panel-mounted CRTs to "paint a picture" of the proposed instrument panel configurations is one way to achieve rapid display reconfigurability.

Key Issues Regarding Driving Simulators

In the aircraft industry, sophisticated and expensive simulators can be justified on the basis of the much higher costs of flight operations and the need for pilot safety. The costs associated with the development and use of instrumented, variable characteristic test cars are orders of magnitude less than for the case of aircraft, so driving simulators have typically employed relatively simple and inexpensive technology and have been much less realistic than their aircraft counterparts. A new class of high performance driving simulators with computer generated imaging capabilities has emerged with the development of the Swedish Road and Traffic Research Institute facility and the Daimler-Benz facility; and

the Swedish facility is comparable in cost to a variable characteristic test car. The motivation for developing driving simulators is the same as for aircraft simulators; namely, to provide a safe, flexible, convenient and economical means for presenting an operational scenario in a controlled environment with readily available measures of man-machine system performance. Competitive pressures to reduce engineering development costs and design lead times have led to strong interest in driving simulators as a means for evaluating alternative designs and conceptual schemes prior to hard-line design and hardware evaluation.

There are several key issues that we have considered related to the future use of driving simulators at GM. These have to do with the extent to which simulators can be integrated into the engineering process that is being practiced, the ability to achieve the level of fidelity required for different applications, and whether or not one should build, buy or rent time on a simulator facility in order to meet one's needs.

There is no question that even fairly simple driving simulators have value for studies of driver-related characteristics and for research on specific car design factors, particularly those requiring the utilization of a large number of subjects from the driving population. However, to evaluate many subtleties of vehicle design is beyond even the best simulation facilities today. There is no way that current simulation technology can adequately simulate real tires, real suspension bushings, structural vibrations and deflections, etc., all of which are important to the development engineer.

A variety of problems in vehicle engineering involving interactions between the driver and the vehicle can be addressed at very early stages of the engineering process using driving simulators, however. Driver controls and information systems and vehicle directional response characteristics are both fruitful areas for study. Real product development work can probably never be done on a simulator, with the possible exception of vehicle controls and displays; but a lot of the "up-front" work that can influence the overall success of a car program could be done there. Setting performance goals for new vehicles that are significantly different from those currently produced could become very difficult in the future. A simulator could be quite valuable in checking to see that the new goals really do meet product expectations. Having new development engineers spend time on a simulator could speed up the process by which they learn how to relate their driving evaluations to gross changes in vehicle characteristics, such as chassis and tire parameters. Testing could also be done with representative drivers to help predict their response to new product ideas well in advance of product introduction, to establish general human factors guidelines, such as how to best present information on an in-car CRT display, and to establish a data base for determining driver model parameters.

Concluding Remarks

We have attempted to justify the use of driving simulators in the automobile engineering process by listing the advantages and disadvantages they provide with respect to a currently accepted test bed, the variable response car. We have also identified some of the current applications which might be addressed in a simulator and have stated that a driving simulator will not, in the near future, replace testing in a real car. We believe that driving simulators can be integrated into the engineering process but that this is best done in the concept evaluation and functional requirements specification phases and not in detailed design or development.

The 20 million dollar question is, "How much simulator does one need?". By suggesting the separation of the driving task into navigational, guidance and control tasks, and listing some of simulator subsystem requirements associated with this hierarchy, we believe that there are alternatives to purchasing a multimillion dollar facility. One is that a range of part task simulators could be employed depending on the study needs. Another is that a staged or phased design could be followed such that the simulator is developed and applied only to tasks it is suited for and then enhanced to provide further capabilities as needs arise.

By a phased approach, we mean one which starts out with a modest facility that is based on a modular design concept that can easily incorporate future advanced hardware components without the need to redesign the whole system. Such a simulator might start out with a fairly simple color display system of moderate field of view (60°-120°) but with minimal computational lag, a fairly simple vehicle model that can be implemented on a single host computer and a high fidelity steering wheel feel system. This is the approach we are currently pursuing.

With this first phase, simulator tests are best limited to vehicle steering studies in the on-center region (lateral accelerations under .3 gs). A high fidelity sound system and a source of random vibration might be the next low cost, low risk elements to add. A third development phase might be the addition of motion to extend the control envelope beyond the on-center region. The last phase would

take advantage of the continuing downward trend in simulator visual subsystem costs, by enhancing the visual subsystem to support the guidance and navigation tasks. Throughout the simulator development process, special care and good engineering judgement must be exercised to create an illusion of driving that feels natural during normal driving circumstances while still providing useful predictions of driver-vehicle performance under more severe maneuvers.

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The Use of Train Operations Simulators in the Management of Changing Rail Freight Operations

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Abstract

Railways are forced to continually review their operations to remain competitive in attracting new business as well as in retaining existing business. This means reducing costs and improving productivity at every turn and much of this must come from train operations. It means increasing train lengths and car loads as well as reducing crew costs and fuel costs. The train operations simulator can play a significant role in investigating new service design proposals, and in studying and solving operating problems once a service has been established. It can be a valuable learning tool for train operations people at every level. Through the use of the simulator, an understanding of the impact of train characteristics, track gradient, train handling, and human factors on train control can be achieved. This can help in planning and in evaluating productivity initiatives and in reducing costly failures, delays and derailments in the future.

Résumé

Les compagnies de chemin de fer n'ont d'autre choix que de revoir constamment leurs conditions d'exploitation si elles veulent demeurer suffisamment concurrentielles pour conserver, sinon accroître leur part de marché. Aussi doivent-elles trouver sans cesse des moyens de réduire leurs coûts et d'améliorer leur productivité. Qu'il s'agisse d'allonger les trains ou d'augmenter la charge des wagons tout en réduisant les coûts de main-d'oeuvre et de carburant, le mode d'exploitation des trains est au centre de l'exercice de rationalisation auquel se livrent les compagnies de chemin de fer. Le simulateur de conduite de locomotive peut jouer un rôle important dans la mise au point de services ferroviaires modifiés ou nouveaux, et dans l'étude et la solution des problèmes susceptibles de découler de la mise en place d'un service modifié. Le simulateur peut également constituer un outil précieux d'apprentissage pour les personnes responsables de la conduite des trains, à tous les niveaux. Le recours au simulateur permet de mieux comprendre l'influence de divers facteurs, tels que le gradient de la voie, les caractéristiques et le comportement du train et les facteurs humains, sur la conduite du train. Grâce à cette meilleure compréhension, on pourra à l'avenir mieux planifier et évaluer les initiatives destinées à accroître la productivité et réduire au minimum les défaillances, les retards et les déraillements à l'origine de pertes coûteuses.

Introduction

The railways, like all industries, are forced to continually review their operations looking for ways to remain competitive and attract new business or even retain their existing share of the market. Commodities, traditionally handled by rail cars, are now, with deregulation, attractive to the trucking industry. This results in our customers having a greater choice of alternatives and allows them to demand more service at lower costs.

Our viability depends on our ability to increase our efficiency and reduce costs through the use of improved equipment and other productivity initiatives.

Train Operation Simulators play a significant role in this search for ways and means of producing safe quality transportation at a cost attractive to the marketplace.

For those of you not familiar with railway technology I would like to point out that over the last decade our freight train loads have increased from an average of about 4000 tons to some 7000 tons, and our train operation is designed to take advantage of our passing track network of 6000 feet. Our bulk commodity trains like coal consist of 98 cars, weighing over 13 000 tons, and are designed to operate at moderate speeds.

The standard box cars are gradually being replaced by specialized equipment such as covered hopper cars (for minerals, chemicals, and grain), bulkhead flat cars for lumber, intermodal cars for container and highway trailers – just to mention a few obvious examples.

Before discussing the Train Operations Simulator as developed by CN and how it is used in studying

possible changes in operations I would like to briefly describe the essential components of the CN Locomotive and Train simulator. These components must be included and modelled accurately in order to obtain reliable results from which safe operating practices can be implemented, some of which can involve the spending of large sums of capital for plant and equipment.

Essential Components of the Train Operations Simulator

(1) Longitudinal Train Dynamics Model

In a freight train each car is connected serially to the adjoining cars by a system that includes in addition to the couplers a shock absorbing device that is normally inserted in a yoke arrangement. This device is often referred to as a draft gear. When the couplers are stretched or compressed due to different velocities of adjoining cars, energy is absorbed by this device as it is compressed in the yoke. There are also certain amounts of free slack inherent in such an arrangement as well as in the couplers themselves.

The longitudinal train dynamics model calculates the train dynamics (or slack action as it is often called) and in-train coupler forces resulting from the relative velocities produced by the differential forces acting on each car or block of cars. These forces are the external forces due to track elevation, curvature, and rolling resistance – and the internal forces of locomotive tractive effort and brake retardation. Particular emphasis is placed on the transient in-train forces produced by train handling and track profile.

The model then consists of a series of individual masses coupled together by nonlinear spring elements (of considerable complexity – including the car body stiffness and free slack) and acted upon by these external and internal forces.

The simulation of this model involves the simultaneous solution of the equations of motion for as many cars as the train you wish to simulate. This is done at CN by analog as well as digital integration techniques. The analog simulation uses a hybrid computer capable of simulating a 120-car train whereas an all digital computer model is used to handle longer trains.

(2) Air Brake System

The response of the train air brake system must be calculated for every phase or mode of operation including:

- emergency applications
- service applications, including minimum, partial and multiple applications
- recharge and cycle braking

A train air brake system is a very complicated system in which compressed air is supplied by the locomotives to each car in the train by a single pipe running the length of the train (typically 6000 ft). This brake pipe, as it is called, is also used as a signal line to apply or release the brakes on each car (in a more or less serial manner).

Using this signal line the locomotive engineer can apply a given amount of retardation. He can make incremental increases in the amount of retardation, but the system will not allow a partial release if too much braking effort is obtained.

Basically each car has a reservoir to store air and a very important component called a control valve which responds to the local pressure of the brake pipe by directing this stored air to brake cylinders on the car or by releasing the air from the cylinders.

The simulator must contend with all the variation and complexity of air brake equipment. For example, there are 3 or 4 different car brake control valves which must be considered, each one an enhancement or modification of an earlier model. Faster application times, faster brake cylinder rise times, and faster release times are some of the more obvious differences.

Railway equipment evolves slowly over time and air brake equipment and components are no exception. Therefore, many ages and variations of this equipment must co-exist on any given train at any given time.

(3) Motive Power Units

In most cases these functions are fairly straightforward to model and control as simulator inputs. The diesel electric tractive effort characteristics are well-known functions of traction force versus speed for each constant horsepower level. The throttle normally selects 8 reasonably constant horsepower levels.

Some locomotives have a dynamic brake system which converts mechanical energy from the wheel and traction motors to electrical energy, and regulates the transmission and dissipation of this energy in dynamic resistors or brake grids.

Wheel rail adhesion and the wheel slip control system is somewhat more difficult to model and sometimes must be averaged or idealized.

(4) Locomotive and Freight Car Characteristics

Certain car data is essential as input to the simulator program. Most importantly the coupled length of each car and the weight of each car. Unfortunately, the actual weight of some cars is difficult to know with certainty – often estimated within 10 to 20 percent.

The mechanical brake equipment on each car, including brake cylinder, brake levers, slack adjusters, and brake shoes, all respond to the air brake system to provide a suitable retarding force to each car. In fact, each car can produce widely different brake retarding forces. This is especially a problem between empty and loaded cars, and is the cause of some high levels of train action.

The braking parameters of each vehicle include the designed brake ratio, which defines the force available to the brake shoes, and the brake efficiency, which takes into consideration the losses due to the individual cars brake systems design and complexity. The coefficient of friction between the brake shoes and the wheel tread is one of the most difficult parameters to characterize and to know with accuracy.

The characteristics of each draft gear or end-of-car cushioning device must be known for each car in the train. This includes a wide variety of such devices:

- standard friction gears (low and high capacity),
- rubber/friction cushioning devices,
- hydraulic end-of-car cushioning draft gears,
- sliding centre sill devices.

Rolling resistance coefficients must be specified for each car type. These coefficients are based on the common quadratic form known in the railway industry as the Davis Equation.

Standard car types include box cars, flat cars, container cars (including double stack containers), tri-level auto transporters. Of course with some cars, the aerodynamic resistance depends on whether they are loaded or empty – e.g., container and bulkhead flats. Even alternative freight car truck designs which include innovative self-steering mechanisms have been included in our studies.

The introduction of integral freight cars or 5 Pacs as they are sometimes called has also been studied. These are typically 5 freight cars rigidly coupled, i.e., without coupler or draft gears, and often with only one truck per platform (i.e., where each end of adjoining platforms is mounted on a single truck, referred to as an articulated car).

(5) Track Profile Data Base

A great deal of care is taken to prepare and maintain an accurate track data base even if it means re-surveying the profile and curvature for any given route. This procedure is almost automatic following a derailment.

Outline of the CN Train Operations Simulator Capabilities

Real-time Simulator for Training and Research

This simulator option includes an actual locomotive control stand (totally functional) interfaced to a mini-computer. This facility was the forerunner to the CN Training Simulators used today in Gimli, Manitoba. It has withstood the test of time and has been utilized as a research tool countless times since the mid 70s. In many cases it has been modified and reprogrammed to suit each unique problem and has proven itself again and again against numerous field tests as well as against actual operations.

The simulator is also interfaced to the analog longitudinal train dynamics computer (mentioned above). The analog computer is totally programmable from the host mini-computer. This includes configuration of the analog model (number of vehicles, car weights, draft gear parameters, scaling, etc.), complete control of the analog computer, as well as providing the external/internal forces acting on each car (normally once per second).

The hybrid/analog computer is capable of handling up to 120 cars and relieves the host computer of the tremendous computational burden of solving 120 simultaneous differential equations. The hybrid can be programmed from the host to return any of the internal analog variables – forces, velocities, accelerations, displacements – via an A/D interface, as well as to enable up to 16 analog channels of any variables (normally coupler force) at any location in the 120-car train model.

The operator drives the simulator using a graphical display of the train's location on the selected profile and track plan. A computer terminal and the control stand (with analog gauges and indicators) provide key information on the locomotive and brake system. On a third display screen the response of the longitudinal model can be monitored. This screen shows the forces acting at each coupler down the train as well as any one of the other three variables.

Digital Train Dynamics Modelling

At CN Research, we developed in the late 1960s a digital longitudinal train dynamics model to study

serious problems encountered with hydraulic EOC cushioning devices. Hydraulic draft gear was coming into train service in great profusion at the time. The model was to investigate the problem, test possible solutions, and determine which designs were satisfactory without continuing with expensive and cumbersome road testing. The problem was determined to be that the hydraulic units were essentially designed for yard impacts and were not suitable for in-train service, especially when marshalled in large numbers.

This model was not intended as a train operations simulator and was run in a limited batch mode on one of the most powerful IBM main frames of the day. Then it was very slow and very expensive to execute – many hundreds of dollars per minute of real time simulated.

Today this same digital model is used in a detailed Train Operations Simulator which runs on a powerful desktop computer. This simulator can handle longer trains with greater flexibility than before and provides an ideal tool for studying train dynamics and general train operations without the complications of providing an expensive locomotive environment (and in real time up to 100 cars).

Control is provided via the computer keyboard (with simple key strokes) and complete input to the operator is provided via a VGA colour screen including location, track information, the state of the locomotive and train and detailed picture of the train dynamics. We have only recently adapted our simulator software to this rapidly growing PC environment and we are in the process of expanding and enhancing this facility.

Figure 1 is a sketch made from the colour graphics display screen showing the instantaneous coupler forces at each car in the train. The display shows a train descending a very steep grade as the leading end is entering an ascending grade. This is an actual 100-car coal train on one of our coal branch lines. Figure 2 represents the time history (over a 100 second interval) of the longitudinal coupler forces acting between cars 80 and 81 starting from the point of time represented by Figure 1.

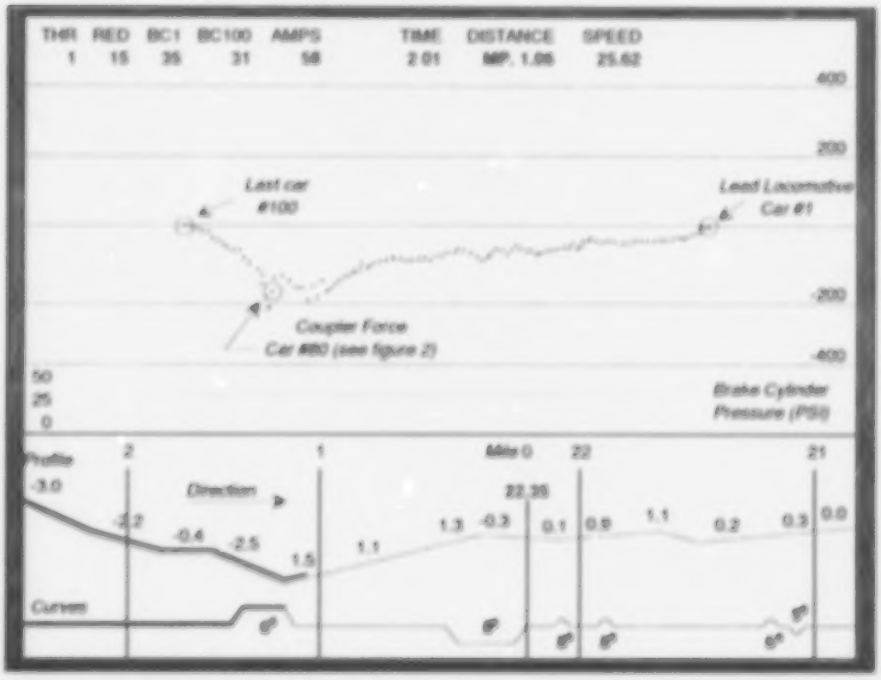

Figure 1: Digital Train Dynamics Screen Display Showing Instantaneous Coupler Forces with Train Location on Profile

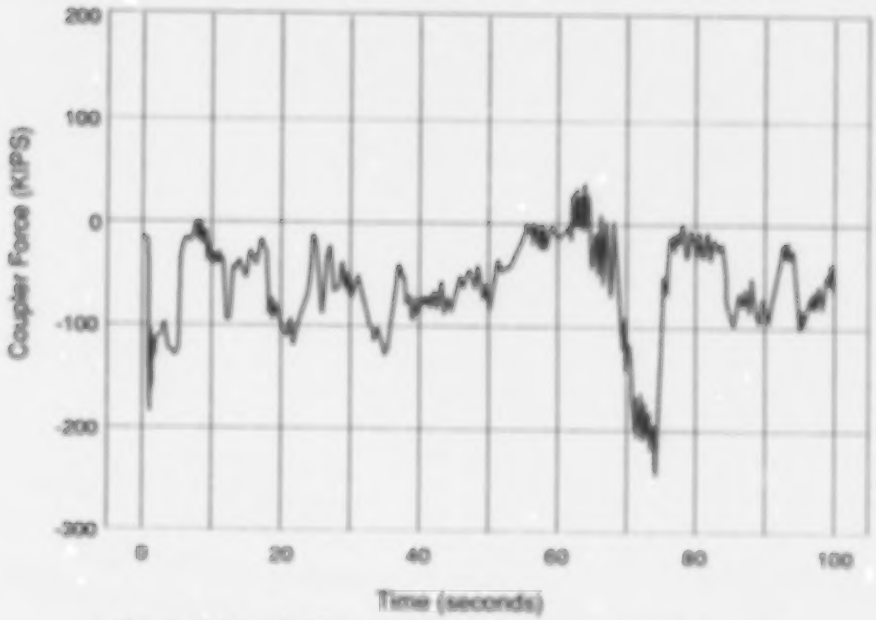

Figure 2: Coupler Force at Vehicle 80 (100 second interval)

Applications of the Train Operation Simulator

(1) Service Design

The CN Research train operations simulator is used in many ways to study options to improve train productivity. In many cases this involves simulating train operations where it is desired to increase the length of certain trains. For example, on one of the coal branch lines the trains were doubled from 50-car cuts to full 100-cars trains. In these cases field personnel were brought in to study the train handling problems, to share their experience and to perform numerous simulation runs to gain confidence with the longer trains.

Often in service design studies it is found that certain equipment modifications must be made – for example, all locomotives must be equipped with dynamic brake, air brake retainers may be required, all cars must have high strength draw bars.

As I mentioned before, the introduction of 5 Pac cars have caused concern and simulation studies have been performed to investigate these concerns. For example, when an articulated 5-platform car weighing over 600 000 pounds is included in a conventional train, what impact will it have on longitudinal train dynamics? From these studies we have found how to best marshall 5 Pacs and we have gained confidence in operating these trains.

Recent productivity initiatives have required that we study the prospects of extending train length from the present 100-car limit (of 6000 ft.) up to 200 cars. These studies include the placement of remote locomotives in the train and the problems of braking control and air supply associated with such long trains.

Studies aimed at increasing train movement productivity in hump yards have utilized the train operations simulator. One project involved doubling the number of cars taken at one time into the humping process. Here the simulator was modified with the detailed hump yard locomotive consist including pacesetter control (which is a constant speed controller used for loading and humping operations). The simulations involve moving up to 180 cars in a pushing movement up to the crest of the hump and then humping the train at a constant speed (e.g., 1.5 mph). The points of interest here were the time required to make each movement, the ability of the locomotives to start and stop a train of approximately 12 000 tons in a yard (with poor rail conditions) using engine brakes only, and the

high longitudinal in-train compressive forces which can cause derailments especially in yard tracks.

Another yard study involving the train simulator was in the development of an automatic LCS – Locomotive Control System. In this system, the LCS yard locomotive consist is unmanned and is controlled remotely by radio from a central location or from a man on the ground. The operations simulator was used to create movements and situations which were similar to the environment under which the LCS locomotive would operate. These include simulating braking distances, stopping, holding and lifting capabilities at all locations and under all conditions, and monitoring in-train forces at all times.

(2) Operating Problems

Another general area of application for the Train Operations Simulator is in solving day to day operating problems for our Transportation Department. In a large part this involves train handling practices and working with field personnel (locomotive engineers) on the simulator to determine better methods of train control.

A major effort over the years has been in the study of fuel savings and much effort has been to reduce the practice known as power braking. This was a common practice essentially to reduce slack action where the engineer would apply some amount of train brakes and then continue for long periods of time to work high amounts of power to maintain track speed. The purpose was to keep the train stretched and avoid train action but the practice was abused and rarely offset the extreme waste of fuel and brake shoes, not to mention the harm done to wheels which must absorb the heat generated.

Using the simulator, we were able to demonstrate the high cost of power braking and show that there were other ways of train handling which are just as safe for train action. This process involved much simulator training and it generally lead to positive results since the crews were able to see the results. Some railways in the US penalize crews for use of the train brakes when dynamic brakes are available.

In trying to solve some operating problems with the assistance of field personnel, the first objective is to gain the confidence of the train crews in the simulator process. This means having them operate over track well known to them and with train characteristics (tonnage, braking, etc.) which reproduce the same response they normally experience in the field. In most cases this requires concentration on only a few specific variables – train speed, location, the train controls and gauges and, most importantly, the train dynamics display itself. The train dynamics monitor is an X-Y graphics display showing the forces of buff and draft at each coupling in the train, as well as the relative displacement or slack between cars. For our purposes, the human factors of the environment (e.g., sound, motion, visual inputs) are not important and may even be distracting.

The incident of break-apart caused by high in-train forces can also be reduced by experimenting on the train operations simulator. This problem has been resolved very successfully in many locations across the CN system by this process. In some cases the coupler/drawbar assemblies have been weakened over time and train handling practices must be modified in order to avoid the high forces which fatigue this equipment and ultimately cause such failures.

In some cases we have introduced pusher locomotives to avoid the high concentration of steady drawbar force caused by placing too much tractive effort at the head end of the train. The simulator has been used in determining the best use of these pushers.

Another cause of break-aparts was found to be a combination of train marshalling (weight distributions) and track profile. On the undulating profile of the Kingston Sub. the wave length or peak to peak distance was approximately 6000 ft, which matched the length of trains being marshalled out of Toronto Yard. In addition these trains had heavy loads on the rear and on the front end with predominantly empties distributed throughout the middle. This dumbbell type train caused numerous break-aparts using normal train handling procedures. Much experimenting on the simulator and in the field finally identified the problem, which was eliminated using alternative handling procedures.

Another operating problem is in grade braking, especially where restricting signals and train meets must occur. Here the problem involves careful use of the train brakes in order to avoid stalling on the grade, depleting the air supply through cycle braking, and most of all passing the red signal (even by a few feet). The simulator is used frequently to determine the best way to manage the brakes on the grade and to study the options available in the event of stalling (i.e., when there is not enough tractive effort to move the train against the brake). Note that once a heavy train is stopped on a steep descending grade, caution must be taken before any releases of the brakes – depending on the state of the air system and track clearance.

The train simulator has been used a great deal to alleviate fears and misconceptions among train crews as well as among management, and has provided confidence in many operating situations.

The main human factor which must be dealt with is the confidence in the simulator; does it agree with field experience, and if so, will the experience gained on the simulator be applied in the field?

(3) Accident Investigations

The train operations simulator also provides useful insight into the possible causes of an accident. In this regard the CN Research simulator is well suited to this application because of the ease in which we can adjust different parameters to accurately reproduce the unique conditions surrounding each accident.

In many railway locomotive and train simulators (especially in training applications) these parameters are not normally available to the user and often such parameters represent average conditions that may not be adequate to study the circumstances that lead to an accident or derailment. In many cases a detailed parametric study is required in the process of analyzing one derailment. As well as track speed (or overspeed), the response of the train dynamics model is one key element in each study, and in particular the forces encountered at the first derailed car as it reached the point of derailment. The magnitude and nature of the longitudinal forces (buff or draft, and the duration) and the location of the car on track (whether in a curve, spiral, or tangent track) can be very important in interpreting the cause.

The simulator does not model individual lateral and vertical forces acting at each car wheel due to the immense amount of computation required and the detailed track and car data required to perform these calculations. This analysis can be performed off line by specific vehicle dynamic models if the results of the simulator indicate that serious longitudinal forces could have occurred at the critical location or moment in time.

The introduction of event recorders on locomotives in recent years has greatly assisted in investigating certain derailments, especially with respect to train handling. With a record of train speed and train control settings, we can take better advantage of the flexibility of the research simulator. Without the event recorders, the simulator must also be used to verify the crew's statement on how the accident occurred and often to perform many emergency stopping distance simulations in order to estimate the speed at the point of derailment.

It must be understood that as the name implies the event recorder only records the timing of certain events – speed, brake and throttle control changes, but it does not provide the location of these events. The locations must be determined by integration of the speed record and with this, one must provide accurate reference locations and resolve the problems of speedometer errors (wheel slip, locomotive wheel diameters).

It is not my intention here to list accident investigations we have been requested to simulate; however, I should mention a few in passing, such as the 1986 Hinton accident. In this tragic event a westbound train contrary to signal indication did not stop at the end of double track and collided head-on with an opposing train, only seconds after entering single track. Our simulations of this event collaborated all the available field data (timing of events) to within a few percent of error, and therefore helped confirm the cause of the accident.

In another derailment investigation the simulation showed that the derailment occurred due to high in-train forces produced while the train was being decelerated by an unintentional emergency brake application.

In many instances the simulations have enabled us to determine the influence of such things as track gradient and alignment, as well as train marshalling, makeup and train handling on the cause of derailments.

(4) Advanced Train Control System

At the present time the North American railway industry is looking at the possibility of using the latest developments in computers and communications technology to aid in the control of trains. The emphasis for this system, known as ATCS, is in railway operations safety, but efficiency and cost over existing control systems is also a benefit.

A joint project group was set up to prepare performance specifications. Part of CN's contribution was to investigate locomotive cab displays in terms of what information and how should it be displayed. CN was selected to conduct this study on one of our full-size training simulators at Gimli, Manitoba. Of course, the main emphasis for this environment was to study the human factors element, vis-a-vis the display monitor and the engineer's job of controlling the train. Such factors as eye contact and the level of distraction to the locomotive engineer were monitored. The general usefulness of this display in planning his train handling activities were studied, as well as many other factors that could influence his ability to safely handle the train.

Other aspects of the ATCS project where we were able to contribute because of our experience with train operation simulations was in developing a predictor/enforcement algorithm. This algorithm

predicts the train speed and location every 60 seconds based on the current state of the train and locomotive controls, as well as the minimum possible stopping distance. Based on the result of the algorithm the ATCS on-board computer has the information to override the engineer if a violation is pending, and especially to automatically apply the train brakes to avoid proceeding beyond an end of authority.

Concluding Remarks

This paper has stressed the use of the train operations simulator as a tool in evaluating train operations in an increasingly competitive marketplace. No stone must be left unturned in management's drive for more productivity at the lowest possible cost. As we all know, the railway is the safest and most energy efficient mode of land transportation, but it is also very capital intensive, and therefore, making the maximum use out of this capital investment is essential to its survival. Productivity can only be achieved by minimizing the costs of operations, and accidents and derailments can be a big part of this cost. It is in careful planning and evaluating of all the options that the train operations simulator can be used as a valuable development tool for railway management.

A Seaman's View of Marine Simulation

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Abstract

In 1982 the loss of the MODU *Ocean Ranger* with all hands led to a Royal Commission of Inquiry whose report included a recommendation for provision of ballast control simulator training.

In 1984 the Institute for Marine Dynamics commenced work on conceptualising a simulator appropriate for a broad area of marine activity including ballast control operations, based on many years of experience in training using part-task, radar and static bridge simulators.

This work involved a study of marine simulation state-of-the-art worldwide and development of training and applied research objectives of interest to Canada and the international marine community.

In 1987 the Canada/Newfoundland Offshore Development Fund approved $12m for a Marine Offshore Simulator Training and Research Centre (MOSTRC) leading to a Functional Specification, Tender Call and associated Due Process with anticipated commissioning in 1992.

Since funding, the Institute has commenced program development, with Instructors attending so far 36 person-weeks specialist courses in full-mission marine simulation operation on eight simulators worldwide, with the goal of identifying trainee performance objectives and development of training manuals.

The paper discusses events to date and how well MOSTRC and simulators generally can, for example, reduce an 80% operational (human) error cause-attributable, particularly regarding recent marine catastrophes.

The paper asks whether an era of automation and increased technological complexity is really at hand, and whether safety is always a paramount factor in the area of marine transportation, concluding with a seaman's opinion of the present and future value of marine simulation, addressing the benefits and some of the difficulties associated with the acceptance of simulation in a very traditional industry.

Résumé

Le naufrage en 1982 de l'unité mobile de forage en mer « Ocean Ranger » et la disparition de tout le personnel à son bord ont fait l'objet d'une Commission royale d'enquête qui, dans son rapport final, a fait une recommandation concernant la nécessité d'une formation sur simulateur en contrôle des ballasts.

En 1984, Marine Institute a commencé l'étude conceptuelle d'un simulateur pouvant convenir à une vaste gamme d'opérations maritimes, y compris le contrôle des ballasts, tirant parti de la grande expérience en formation acquise au fil des ans sur les simulateurs de tâches partielles, radar et passerelles de navigation à l'état stationnaire.

Il a fallu pour cela faire un tour d'horizon sur l'évolution dans le monde en matière de simulation maritime et définir les objectifs devant être fixés à la formation et à la recherche appliquée pouvant intéresser les milieux maritimes du Canada et d'ailleurs.

En 1987 fut approuvé le Fonds Canada/Terre-Neuve de développement des régions extra-côtières d'un total de 12 millions de dollars destinés à la création d'un Centre de formation et de recherche par simulateur d'opérations de forage en mer. Dans la spécification fonctionnelle, l'appel d'offres et la procédure associée, la mise en service du simulateur avait été prévue pour 1992.

Le programme de développement lancé depuis l'approbation du Fonds a permis aux instructeurs de participer, au cours des 36 semaines-personnes achevées jusqu'ici, à des cours de simulation maritime générale sur huit simulateurs un peu partout dans le monde, avec la tâche d'élaborer les objectifs devant être fixés à la formation et de rédiger des manuels de formation.

Cette communication récapitule les événements et montre à quel point il est possible, grâce à ce Centre de formation et de recherche, de réduire les taux d'accidents, notamment les 80 p. 100 attribuables aux erreurs humaines, à la lumière des récents naufrages en mer.

Les auteurs se demandent si vraiment nous sommes à l'orée d'une ère d'automatisation et de

technologies de plus en plus complexes et si, dans ce contexte, la sécurité se trouve toujours au centre des préoccupations en matière de transport maritime. Ils donnent le point de vue d'un marin sur l'importance actuelle et future de la simulation maritime, dont ils expliquent les avantages et les inconvénients, surtout au regard d'une profession forgée dans le traditionalisme conformiste.

Introduction

This paper discusses marine simulation using a "full-mission ship's bridge" within a commercial rather than military environment. The Institute for Marine Dynamics does not have such a device and we can only present an attempt to defend a definition, rather like describing an elephant by saying "we know one when we see one".

Ordinarily this would be reason for an immediate and undignified retreat from this podium, however, the Institute is in the precise and measured process of acquiring a $12m "full-mission" ship and ballast control simulator into which six years of research and $100 000 of operator training has already been invested. This activity is within the context of many years research and training experience with part-task and "not so full-mission" simulators and in the sense that all training, and possibly education, is simulation.

Hence we feel we have learnt a lot, certainly in setting objectives appropriate to the type of simulator specified. Also, since all systems we have seen have cons as well as pros, not presently having a simulator removes the human tendency to defend the system you have persuaded someone to purchase at a cost of millions.

Definition

As for "full-mission", we describe this as a full-sized ship's bridge complete with mainly real controls/instruments, which may or may not be mounted on a motion platform, surrounded by a screen at sufficient distance to give depth perception, upon which there is an image of the environment, all computer driven in real time using six degrees of freedom mathematical models.

This definition is not elegant but is necessary in a world where "marine simulator" means many things to many people.

The definition also may be considered only as our opinion of what a full-mission simulator should look like, based on our feeling that it should be as realistic as the budget allows, as near the standard of realism of, say, the nearly exact aircraft or nuclear power station simulators.

(Later in the paper comparison is made between marine and aircraft simulators).

Other opinion is that most of our training, though probably not all of our research, objectives can be attained with a simulator simpler than "full-mission", well substantiated by Part Task Evaluation (1), concluding that small less expensive simulators may meet most basic and intermediate level shiphandling skills and be just as effective compared to full-bridge (mission) shiphandling training, and by such research as on development of a Canadian Arctic Bridge Navigation Simulation by Fleet Technology Ltd. (2), which company is in our opinion a world leader in vessels-in-ice simulation development.

To us the discussion on "levels of realism" is strange because as in aircraft and power stations, if you are going to acquire a simulator surely the nearer to the "real thing" the better. After all you can buy a PC program simulation of an F-16 fighter plane, but after such "training" you may hesitate to step into the cockpit of the real thing. However, confidence would no doubt be higher after training on a full-mission simulator complete with G-suits.

Full Mission and the "Real Thing"

Some of the practicalities of the "real thing" in a ship sense are mentioned later, but not buying a "full-mission" simulator may well be occasioned by lack of funds or concerns regarding guardianship of the public purse, rationalized by reference to Flexman's correlation (3) between exponential increase of cost and logarithmic increase of fidelity, both related to training value. This research was done in 1965 and supported in 1978 by Zade (4) who also drew attention to the difference in design and technical realization of ship versus flight simulators (of interest in our own Performance Specification situation).

Further rationalized by the statement that the instructor matters more than the equipment, a good instructor with bad equipment is better than the reverse (and this is certainly our experience as "students" in simulation schools), but the best surely is a good instructor with good equipment.

However, much has happened in the world of electronics and computers since 1978 and certainly since 1965, so today how valid is the familiar exponential curve of cost versus training value? Cannot new technology provide more realism at less cost? We think it can, and if so, this raises an ominous

question, are there other reasons for not having a full-mission simulator? Remembering that the marine industry is very conservative, more on this subject later.

Background to the Institute's Simulator

The Institute's interest in full-mission ship simulation goes back to 1976, about six years after what some consider the "birth" of marine simulation in the Netherlands. However, the graphic milestone for our efforts to acquire a marine simulator occurred in the early morning of February 15, 1982 with the loss of the MODU *Ocean Ranger* with all hands.

The Royal Commission (5) into the loss stated "During the Public Hearings attention was focused on the training of ballast control operators. Neither of the two operators on the *Ocean Ranger* at the time of the loss had received any formal course of training but had learned through on-the-job experience. No formal training or testing was required by regulation. There was no manual available which fully described the operation of the ballast control panel or provided detailed drawings of the components of the panel. Because of the critical function of the ballast control operator, specific recommendations are made with respect to training..."

There followed Recommendation #35, which in respect to Ballast Control Training included instruction in the practical operation of a ballast system by simulator and on a rig itself when available.

Hence the inclusion of a ballast control simulator in our $12 m package, recognizing that the philosophies of ballast and ship simulation training are the same.

However, in a conservative environment progress is not always rapid, and in 1986 a Government of Canada Response to Ocean Ranger Recommendations (6) referring to #35 noted that "... a simulator may not be used in all cases – trainees receive practical supervised exercises on MODUs," but how realistic can such exercises be on a working rig? Early 1993 should see the commissioning of such a simulator in Newfoundland, with applications to other forms of vessels as well as to floating and bottom-founded offshore installations.

In 1984 the Institute commenced work on conceptualizing a simulator appropriate for a broad area of marine activity including ballast control operations, based on many years of experience in training using part-task, radar and static bridge simulators.

This work involved a study of marine simulation state-of-the-art worldwide and development of training (7) and applied research (8) objectives of interest to Canada and the international marine community.

Also between 1984 and 1985 the Institute assembled what was probably the first Canadian attempt to use part-task training equipment (mainly from NorControl) to form a Bridge Simulator using $800 000 from a Skills Growth Fund. This is called the "Static Bridge" which will now be itself a "part-task" trainer as part of the full-mission and ballast control simulators.

In 1987 the Canada/Newfoundland Offshore Development Fund approved $12m for a Marine Offshore Simulator Training and Research Centre (MOSTRC) leading to a Functional Specification, Tender Call and on 90-10-18 Award of Principal Contract to NorControl Simulation Ltd. of Norway, with scheduled commissioning in Spring 1993, in good time to host MARSIM '93 in June.

Since funding, the Institute has commenced program development, with Instructors attending so far 36 person-weeks specialist courses in full-mission marine simulation operation on eight simulators worldwide, with the goal of identifying trainee performance objectives and development of training manuals.

In our opinion there is no better way to study the operations of a simulation school than by attending a course as a trainee, either as an Institute group or – even better – as an individual amongst a group from other areas. This is where the "trainees" are themselves "of the cloth", that is professional seamen and educationalists.

We have much to learn and some things still puzzle us, such as the "clowning around" done at many schools. For example, trying to land a commercial jet on an aircraft carrier accompanied by graphics of a young person undressing; before an inevitable collision playing the theme from "Jaws" and afterwards the sound of breaking glass and graphics of King Neptune. All this is against educational theory, but these schools have a lot of experience...

Philosophy of Simulation

Simulator training is effective where errors of judgement can endanger life or property. Simulator training can provide efficiency where a number of tasks must be undertaken by one person and where priorities among these tasks may change with changing circumstances (9).

Accidents resulting from human error are caused by bad decisions and by lack of knowledge. Knowledge can be provided through other means; however, decision making can only be improved by providing experience and training. Effective simulator training can reduce accident rates and improve operating efficiency.

Simulator training is decision-making training which provides experience to improve a person's judgement, thereby allowing that person to make better decisions. The effectiveness of the simulation training can be measured by monitoring the decisions made, particularly in unusual, difficult or confusing situations as shown in research such as that conducted at the College of Maritime Studies, Warsash (10).

A simulator reproduces life-like experiences in which decisions are required. Each learning experience must challenge the trainee at all levels of experience. Trainees must be stressed beyond their current level of experience in each exercise in order to gain more experience. The forced decision making allows trainees to build better judgement skills.

Simulation highlights human reactions in stressful situations and only the morale of the trainee suffers when mistakes are made. The experience gained will help to prevent the same mistake from being made in the future.

Canadian Statistics

Each year the marine casualties branch of Transport Canada publishes statistics related to marine accidents involving Canadian ships in all waters and all ships in Canadian waters.

The investigations into these incidents yield information pointing to the causes. In 1987 the proportion of accidents attributed to human error was 47.1%. In 1988 the number of incidents in the four categories rose significantly and the proportion which were attributed to human error also rose to 56.6%.

It is unclear what the underlying causes leading to human error are in these cases. Various incident reports refer to reduced manning, overwork, unfamiliarity with new technology and other such contributing factors as possible reasons for poor decisions being made. Perhaps the one common underlying factor which is almost never cited as a cause of these incidents is lack of experience.

Lack of experience is a factor in all accidents. This is not an unreasonable statement since the type of experience required in these incidents is experience that is not only potentially dangerous to accumulate but also highly undesirable.

Experience versus Training

Many will maintain that "there is no substitute for experience" and, to some degree, they are correct. It would be ludicrous to believe that a person could be trained to become a competent ship-handler through exposure to printed material and lectures on the subject. Competency as a ship-handler must come as the result of both theoretical knowledge and practical experience. The skills required to be a good ship-handler can only be acquired through practice.

Although the preparedness of new watchkeeping officers is a subject of international concern (11), maritime countries who issue certificates of competency to mariners have rarely become involved with regulating the quality of the experience which a ship's officer receives on the job. There is no requirement, for example, for a first officer to dock or undock a ship a number of times under supervision of a qualified Master before being given command of a ship. In reality most mariners who dock a ship for the first time will do so only after they have been promoted to Master.

The quality of the experience gained on the job may also be brought into question since it depends on the quality of the experience of the person who is supervising the training.

The Role of Simulation

Simulation is not a substitute for experience. In fact, simulation is experience. Simulation experience can be better than real life experience in many instances, especially in situations where conditions can vary. Very few persons would want the experience of docking a ship for the first time with heavy wind conditions, however, simulation can provide this experience many times without risk of accident.

Experience gained in real life situations may not be quality experience. Officers training on a ship where operations are carried out in a disorganized manner may form bad habits that may persist throughout their career. On the other hand, officers who are exposed to high standards of training through simulation may be able to overcome the influence of working on even the most disorganized of ships.

The benefits of providing experience through simulation can be seen as a general improvement in the standards of officers in charge of ships. The experience of simulation, even if it does not cover all aspects of ship operations, will serve to give ship's

officers confidence in their ability to perform. These officers will be capable of immediately undertaking their duties both safely and efficiently. Good habits formed by proper training will be retained and passed on to future junior officers who may not have received this type of training.

Simulation is not new to the marine industry. Radar simulation courses are prerequisite to the issuing of a certificate of competency in all major maritime nations. In recent years ARPA training has become mandatory in most countries and this also requires training to be done on a simulator. There is no question as to the benefits of radar and ARPA training, therefore it is accepted by shipowners, mariners and regulatory agencies.

Ship simulators have been around the marine industry since 1970 or before and the benefits of the training provided by these simulators are as easily recognizable as the benefits of radar simulator training. The major difference is that the benefits of ship simulator training have not yet been recognized by the majority of shipowners, mariners and regulatory agencies. Once this recognition is given ship simulation will become mandatory in many maritime nations. It is true that some countries have given a remission of sea service requirements for ship simulator training but they have not yet made the training mandatory.

The two major uses of ship simulators are training and research. The training can be broken down into two main categories: ship handling training and emergency response training. The research component can be divided into development and investigation. A recent example of investigation using a ship simulator was carried out by CAORF (Computer Aided Operations Research Facility) at King's Point, New York for the US National Transportation Safety Board (12) into the grounding of the *Exxon Valdez*. This study draws attention to the value of voyage preplanning and an understanding of vessel dynamics. It is ironic that the conclusions reached by the investigation using the simulator will probably be accepted with few questions while the value of training provided by the same simulator, which may have prevented the incident from occurring in the first place, will go virtually unrecognized.

At present there should be no surprise at incidents like the *Exxon Valdez*. Study after study for many years has pointed to often quite simple procedural errors resulting in terrible catastrophe. We must ask ourselves, is it really reasonable for only one person to be on the bridge in close waters in charge of an immense ship with a valuable (and dangerous) cargo capable for great environmental damage? A few years ago there would have been two officers on the bridge in situations like the Valdez so that, as on aircraft, each could check on the other.

As was stated by a 1988 Nautical Institute Report (13), "when considering bridge manning the principle must be established that no error or omission by one person should lead to catastrophe". Ten years before in 1978, the U.S. Port and Tanker Safety Act (14) came into force, calling for the qualification for licenses and for the use of simulators for the practice or demonstration of marine-oriented skills. This was followed in 1979 by research (15) showing the benefit of simulator training at no other place but the Port of Valdez.

Another recent incident in the US saw a shipowner's limit of liability denied when it was judged that the shipowner was, among other things, negligent in not providing ARPA training for the ship's officers (Delmorva Power and Light vs Seapride II). It is decisions such as this which give rise to brief periods of increased activity in training. The courts have traditionally seen fit to suspend the license of mariners found negligent in a marine casualty. This serves to remove them temporarily from a position in which they had a deficiency in experience but allows them to return to the same position without gaining sufficient knowledge or training to prevent the same incident from occurring again. A requirement for these mariners to undergo a period of simulator training would better serve to help prevent a reoccurrence of the incident than does a prolonged period of absence from the industry.

A Comparison

Perhaps the best example of successful use of simulation within an industry is in the airline industry. It is difficult to discuss simulation in any industry without trying to draw parallels with the airline industry, bearing in mind the philosophical differences of training for psychomotor response for a fast moving high powered aircraft versus judgement building for a slow moving low powered ship. There are, however, several factors which can be compared in both aircraft and ship simulation which can account for the differences in the levels of success.

Standardization

A typical aircraft simulator is designed to simulate one type of aircraft. This is possible because there are hundreds or even thousands of the same type of aircraft in service worldwide. An airline pilot may in fact qualify to fly a particular type of aircraft without ever having flown in one. This is not meant to imply

that airline pilots do not go through an intensive period of onboard training in addition to simulator training, simply to point out the level of acceptance which simulation has reached within the industry.

Ships, on the other hand, are not standardized at all. There are many different types of ships in service, each with its own particular handling characteristics. Some shipping companies have attempted to achieve a degree of standardization in their fleets but even then ships have different handling characteristics and it is not unusual for ships which are "identical" to have totally different equipment in their engine rooms and on their bridges.

It is because of the lack of standardization that ship simulators, in order to be useful across a wide range of ship mathematical models, must be multipurpose. This in turn makes it necessary for a shipping company to either train its personnel using "similar" models or to pay for the development of a specific ship model. The latter will often cost a large amount in relation to the perceived benefits of training on an exact model. Exact models are usually reserved for research into port or ship development such as the work commissioned by Marine Atlantic in relation to its new ferry *Caribou*.

Company Acceptance

Airline companies have accepted simulation as the only way to provide pilots with emergency training in a realistic environment. It would be inappropriate for airline companies to allow pilots to practice emergency manoeuvres while actually flying an aircraft, with or without passengers. The level of public confidence in air travel safety would be much lower if they were expected to be on an aircraft while the pilot practiced landing without landing gear. Many large airline companies have purchased their own simulators and have made recurrent training a mandatory part of their pilot training programs.

Shipping companies have yet to accept ship simulation as a means of providing training. Shipping companies tend to rely on the job experience of their senior officers; however, as pointed out earlier the quality of this experience is sometimes questionable. Only the largest of marine accidents arouses public concern about safety, yet the smallest of aeronautical accidents brings renewed calls for increased safety in an already safe industry. Perhaps if persons responsible for legislation flew around in ships things might be very different.

However, incidents like the *Valdez* spilling oil and others spilling far more potentially lethal substances appear to be arousing public concern and a demand for more responsible operations in transportation.

Trainee Acceptance

Airline pilots have accepted simulation as an integral part of their training. They recognize simulation as the only practical way to develop and practice the skills they will need in emergency situations to avoid a catastrophe. The degree of automation and movement control in the aircraft industry has made simulation the only means of preparing pilots for emergencies.

Ship-handling is still largely intuitive. This is due in part to the lack of standardization of ships and in part to the many years of tradition within the marine field of placing great pride in one's ship-handling ability. Ships are not automated to any large extent and there still exists an undercurrent of distrust toward anything to do with computers. This has been evident over the years in radar simulation where there has been an immediate willingness to blame the simulator when something goes wrong rather than to look to operator error as the cause. There is still a great reluctance for mariners to accept criticism of their ship-handling skills, especially if they are training with a group of junior officers.

Some of the difficulties associated with acceptance of marine simulation have been mentioned, difficulties which to us do not appear to be insurmountable in view of the well-known causes of accidents and the research that goes back to 1979 at the National Maritime Research Centre, King's Point (16) demonstrating improvement of specific skills, together with later research, particularly with respect to the US Coast Guard Training and Licensing Project (17), where statistically significant results showed the effectiveness of simulator training for cadets, deck officers and marine pilots.

Are these difficulties only felt in the Canadian situation? At a National Conference in 1989 (18) reference was made to Canadians generally not readily identifying with a maritime heritage, and to the low status of the highly unstructured, media-negative Canadian marine industry, despite its huge contribution to the national economy. And Professor Edgar Gold of Dalhousie University referred (19) to the low level of financial support for marine training, except in the provinces of Quebec and Newfoundland.

Perhaps, having only a token national foreign-going merchant fleet, and being virtually dependent on the

ultimately more expensive (20) foreign marine transportation interests, Canadians should not be concerned with simulators and marine training.

But of course we must be concerned since regardless of state flag the activities of ships in Canadian waters affect us all. A 1988 study by the University of New Brunswick Transportation Group (21) drew attention to high Canadian standards compared to many foreign flag vessels at or below International Maritime Organization standards, and to major concerns on the waters around Newfoundland; concerns echoed in 1989 at a Nautical Institute Seminar "Newfoundland – A Jewel in a Polluted Ocean" (read two days before *Exxon Valdez*), at an Institute for Marine Dynamics Seminar "What's a Few Dead Seabirds?", and in a Nautical Institute Brief to the Public Review Panel on Tanker Safety.

Certainly in other areas of the world, Europe for example, there is an increased awareness of the value of simulator training as well as a more draconian attitude towards operators of sub-standard ships, noting that "high-technology" equipment is the exception rather than the rule in the world's 750 000 merchant vessels plying the oceans.

Our own experience is that in the international marine business there is much lip-service paid to safety, but the driver is the financial imperative, the requirement to stay in business, even taking risks that in terms of the environment appear unacceptable.

It would seem common sense that a well-trained marine crew is not only "safer" but more efficient in the sense that ship and cargo will not be lost and the voyage will be completed.

But this connection is difficult to prove, the only way being to have a statistically significant number of identical ships, half with a trained and half with an untrained crew, and study their accident records over, say, a ten-year period. Hardly a practical proposition.

To find the money and make it talk with respect to financial reward for training investment would seem to be the task of marine educators, who as seamen have a deep concern for their environment, no less than for their colleagues on the high seas.

Ongoing research at the Australian Navy ship simulator in Sydney is aimed at establishing such a dollar and cent value, and the results are eagerly awaited.

Conclusion

Based on our work over the last six years the Institute for Marine Dynamics is about to enter the world of full-mission marine simulation training and research with the $12 million MOSTRC.

We are aware of the many research and training opportunities and feel that we are in the same era as was the aircraft industry at the time of the Link Trainer, and that inevitably – and shortly – we will be entering a time where ship, aircraft, and power station simulation all enjoy the same recognition.

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SESSION 3

Human Factors Aspects of Simulators for R&D Applications

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ATELIER 3

Aspects ergonomiques des applications à la R&D

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The Application of Flight Simulators to Studies into Pilot/Aircraft Interactions

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Abstract

The use of flight simulators in studies related to human factors is described by relating experience gained through seven years of operation of the UTIAS Flight Research Simulator. Both applied and basic research applications are covered. The features required of a research simulator are described along with some of the problems facing their operators. It is pointed out that certain aspects of flight simulation make it the preferred method for studying pilot/aircraft interactions in many cases.

Résumé

L'auteur décrit l'utilisation de simulateurs de vol dans les études portant sur les facteurs humains, en se fondant sur l'expérience acquise par l'UTIAS en sept années d'exploitation du simulateur de vol expérimental. Il aborde tour à tour les applications possibles du simulateur dans le domaine de la recherche fondamentale et dans celui de la recherche appliquée. Il énonce ensuite les caractéristiques que doit comporter un simulateur expérimental, de même que certains des problèmes que doit surmonter l'opérateur. Il souligne en conclusion les aspects de la simulation de vol qui en font souvent le meilleur moyen d'étudier les interactions pilote-aéronef.

1. Introduction

The use of flight simulators as research and development tools is now quite widespread. They can be found in the aerospace industry, government laboratories and universities. Because I am most familiar with their application in the university environment I will base my discussion on our experience with flight simulators at the University of Toronto Institute for Aerospace Studies.

2. Facility Evolution

With the current cost of many modern training simulators at well over $10 million, funding would appear to be an insurmountable obstacle preventing any university laboratory from acquiring a flight simulator. Indeed only a very few have. In our case it has been an evolutionary process. In 1964 we were fortunate to obtain a surplus CF-100 tactical trainer from the RCAF. This was a CAE-built fixed-base simulator. Our intent was to employ the simulator in a study on the mathematical modelling of human pilots engaged in tracking tasks. We soon discovered that the effort required to maintain the simulator in its operational state far exceeded our resources. In the end the research was carried out using the simulator cockpit coupled to a general purpose laboratory analog computer.

Eventually a small room was built to replace the cockpit and the CF-100 simulator was scrapped. Our studies of human performance and mathematical modelling continued in this new workstation as we graduated to using digital computers and computer generated displays.

As the work progressed we became more interested in improving the fidelity of the tasks for our test subjects. In particular some of our work would have benefited from the presence of motion cues. At about the same time (1980) we became more interested in the problems of flight simulation itself. Following a concerted promotional effort we were successful in obtaining funding from NSERC, the Ontario Government and UTIAS, gifts from Air Canada and technical support from CAE, which allowed us to make a start at piecing together a research simulator incorporating a modern digital computer and a six degrees-of-freedom motion system. Funding from research contracts was then used to develop the necessary software and interfacing, and over the intervening years, to upgrade various subsystems. The present research simulator is shown in Figure 1. It is presently the most sophisticated flight simulator situated in a university laboratory. However it is not state-of-the-art in several areas. Fortunately many useful studies into human factors problems can be carried out on such a facility.

Figure 1: UTIAS Flight Research Simulator

Depending upon the project requirements a research simulator can be used to simulate an aircraft or another simulator. Also, it is not always necessary to utilize all of the available simulator subsystems and thus part-task simulation is often useful and cost-effective.

3. Research and Development Applications

Research flight simulators are employed in basic and applied research studies. The following examples based on our experience over the past 7 years will serve to illustrate the flexibility of such facilities.

3.1 Simulator Techniques

Projects carried out in this area are aimed at improving the fidelity of flight simulators. The final judge of the success of these efforts is often the pilot himself. The experimental measurements employed can include subjective pilot ratings, task performance, control activity and transfer of training to the actual aircraft task.

3.1.1 Motion Drive Algorithms

The production of motion cues in a ground-based flight simulator is a compromise between generating the large motions which actual aircraft experience and restricting the motion to remain within the physical limits of the motion hardware. A software package (commonly referred to as a washout filter) is employed in a flight simulator to couple the simulated aircraft's motion to the motion system hardware. A number of washout filter techniques had been proposed by 1983 and it was not clear which one was most suited to our developing research simulator.

Three techniques were identified and selected for evaluation: classical washout, adaptive washout, and optimal washout. All three techniques were programmed and integrated into our overall simulation. For each, three versions based on different parameter values were developed giving 9 algorithms in all. The simulator was configured to represent a large transport aircraft during low altitude and ground maneuvers and the different motion algorithms were evaluated by a group of experienced airline pilots. The most useful results were obtained from a subjective rating scale. As a result of this work an adaptive washout scheme was selected as the best overall.

3.1.2 Wind Effects

The involvement of wind effects in the form of turbulence and shear as contributing factors in many fatal aircraft accidents has resulted in the development of wind models for use in training flight simulators. It is felt that exposure to these conditions in the training environment will improve a pilot's ability to deal with wind effects in the operational environment. Our interest in this area was to determine the degree of complexity required for these wind models.

When developing wind models for simulator use, care must be taken to minimize the computer time consumed by them during real-time operations. Four turbulence models and three wind shear models suitable for simulator applications were developed and implemented in software. One version of each represented the state-of-the-art in model complexity. The simulator was configured as a Boeing 747 and a task created involving an approach to landing through wind effects. Ten professional pilots took part in the evaluation process. Once again it was found that subjective pilot ratings were the most useful assessment metric.

The pilots felt that one of the turbulence models in current commercial use (not the newly developed highly detailed model) was the best of the 4 tested. This confirmed that there was no need to develop turbulence models more complex than the one already in use on many training simulators. In the case of the wind shear evaluation, the pilots had some difficulty in providing assessments because they had little operational experience with actual shear conditions. However they were able to confirm that three-dimensional wind shear models of the type that we tested were superior to one-dimensional versions currently in use on some training simulators.

3.2 Aircraft Operations

Two recent projects involved helicopter operations. The current simulator cab contains both a jet transport and a generic helicopter work station. This provides considerable flexibility in selecting research projects in our laboratory. Both helicopter projects dealt with the interaction between the pilot and his visual display.

3.2.1 Pilot Visual Cue Subsystem

The Pilot Visual Cue Subsystem (PVCS) is being developed by Indal Technologies Inc. as a visual guidance system that will enable helicopter pilots to complete safe and reliable shipboard landings with the RAST Mk III system. The latter system is designed to guide the pilot down to the deck and to secure the helicopter once touchdown has been achieved. The PVCS is intended to provide the visual guidance cues necessary to enable the pilot to achieve the initial touchdown.

We developed a part task simulation incorporating an elementary representation of a helicopter and the visual scene that would be associated with landing on a Canadian Forces DDH 280 vessel. The simulation enabled qualified Sea King pilots to experience many of the demands of shipboard landings under a variety of conditions. The simulation included turbulence effects, ship motions and both day and night display scenes. The PVCS is located on the shipboard hangar in front of the hovering helicopter and consists of a roll-stabilized horizontal green bar and a number of lights distributed both horizontally and vertically on the PVCS. The lights are controlled by the position of the helicopter over the ship. Three display configurations were evaluated in the final test program using pilot/aircraft performance and Modified Cooper-Harper pilot workload ratings.

Based on these findings two of the three displays were selected for further evaluation in sea trials. It was noted that the discussion and interaction that occurred among all concerned during the development of the simulation and the drafting of the display dynamics contributed significantly to the refinement of the displays.

3.2.2 Helicopter Flight Director

In order to determine the validity of human factors results obtained in a ground-based flight simulator it may be necessary to repeat part of the evaluation process in actual flight. This was done using our helicopter simulator in the case of an assessment of proposed flight director configurations to aid the pilot in performing instrument landing approaches.

The first step was to configure the simulator to represent the flight vehicle, a Bell 205. This was a lengthy process involving all the simulator subsystems. Once this was achieved, the proposed flight director and its accompanying software had to be implemented and integrated into the simulator.

The flight tests were then duplicated in the simulator using six test subjects having a range of helicopter experience. The primary evaluation measurements were Cooper-Harper handling qualities ratings and workload ratings.

The results from these trials indicated that for the cases where the simulation of the flight director was achieved without difficulty there was excellent agreement between simulated and actual flight. In the one case where the simulation of the flight director was difficult and felt to be not very exact, significant differences were noted with the simulator being much easier to fly than the actual aircraft.

3.3 Basic Research

The research flight simulator finds many applications in the area of basic research. At our Institute work of this type has centred on the sensing of motion and visual stimuli in the simulator environment.

3.3.1 The Sensing of Low Amplitude Motion

The sensing of low level motions by the pilot in the simulator is important for two reasons. Due to the difficulty in providing large simulator motions, the simulator designer needs to know how large motion must be for the pilot to sense motions representing those of the actual aircraft. Also, due to the nature of the motion washout algorithms, there are motions present in a flight simulator that do not have anything to do with the actual aircraft, and the designer would like to keep these so small that the pilot is unlikely to sense them.

In one series of experiments we demonstrated that for sinusoidal motion signals the pilot's ability to detect them can be modelled by signal detection theory. The process of detection can then be described in probabilistic terms with the likelihood of detecting a motion increasing with its magnitude.

In a second experiment it was found that involvement in a flying task increased the difficulty of detecting motions produced by washout filters in the simulator.

In these experiments motion detection was measured by employing forced choice trials in which the pilot was presented with two test intervals of short duration. One interval contained a test motion signal and the other did not. The pilot was required to indicate the interval in which he thought the test signal occurred. The amplitude of the test signal was varied from trial to trial.

3.3.2 Simulator Sickness

Simulator sickness is a term used to describe a number of symptoms that are sometimes experienced by pilots operating a flight simulator. Some of these symptoms (such as dizziness and nausea) may also be found in someone experiencing motion sickness. At the present time it appears that military simulators are involved more often than civil simulators and this may be due to the more violent manoeuvering and low level flight performed in the former.

Our project involves the simulation of simulators having properties that have been associated with simulator sickness. These include a wide field-of-view visual display system and excessive time delays in the generation of motion and visual cues. The purpose of the study is to establish the relationship between the onset of simulator sickness and the level of the suspected stimulus.

Measurements employed include performance, subjective responses to a questionnaire, postural balance tests, stomach activity (EGG) and heart activity (ECG). At the present time this experiment is still in progress and results are not yet available.

4. Research Simulator Issues

Experience with the projects described in Section 3 has pointed out the features required of a research simulator and the problems facing the operator of such a facility.

The following research simulator features may also be found to some extent in a training simulator but not to the same degree:

(1) Fully documented detailed characteristics of all subsystems.

(2) On-site staff who are intimately familiar with all items of (1).

(3) Software and instrumentation capable of measuring both the simulator's and the pilot's responses.

(4) Systems configured for easy alterations to both hardware and software.

(5) Cab of sufficient volume and suitable layout to allow the addition of extra hardware as dictated by project requirements.

(6) Flexible timetables for maintenance, upgrades and project flights.

(7) Access to electronic and mechanical workshops and staff capable of simulator maintenance, modification and upgrades as required.

(8) Multi-purpose software for quick changes to motion system, visual system, instrument display and flight equations.

The following problems face a research simulator group in the university environment:

(1) Locating suitable pilot subjects with the necessary background experience (e.g., may require qualified test pilots).

(2) High cost of transfer of training experiments.

(3) Keeping the simulator hardware and software current. Advances in the training simulator field can be difficult to match due to high costs. As a result some research projects are not possible.

(4) Providing adequate motion and visual cues for operational studies may not be possible with a ground-based simulator.

(5) Funding. In particular the high costs of upgrades may be difficult to finance.

To end on a positive note it can be said that the use of a research simulator provides the following benefits relative to an actual flight test facility:

(1) There are time savings both in setting up the test program and in performing the tests.

(2) It is much easier to control the experimental test environment in the case of a simulator.

(3) The safety of simulated flight allows one to study a wider range of topics in the simulator.

(4) Although they are fairly costly, simulators are often an order of magnitude cheaper to operate than an actual aircraft.

(5) It is much easier to measure and record pilot and aircraft performance in a flight simulator.

Research Issues related to the Use of Simulations and Simulators for Military Vehicles

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Abstract

In this paper, I discuss a number of issues relevant to the use of simulations and simulators for military training. Issues in three domains, i.e., engineering, ergonomics and education, are discussed briefly, with examples drawn from projects at DCIEM related to tank crew training. It is suggested that simulators, used as research devices, can provide useful input to address questions in these three domains.

Résumé

L'auteur aborde un certain nombre de questions associées à l'application des simulateurs à la formation militaire et appartenant aux trois secteurs : technologie, ergonomie et apprentissage. Il en traite brièvement et donne, à l'appui, des exemples tirés de travaux entrepris à l'IMCME en matière de formation d'équipages de blindés. Il affirme qu'un outil d'aide à la recherche comme le simulateur permet de s'attaquer à toutes ces questions.

Introduction

Before discussing some issues relevant to the use of simulators for research, let me briefly describe what I mean by a simulation or simulator. A simulation is simply a metaphor for what is being simulated: it is like the real process, equipment or situation. In this regard, most research can be thought of as involving simulations; the procedures used in research answer *what if* questions about some actual equipment, situation or process. Furthermore, a simulator is the physical embodiment of a simulation. Almost any research apparatus thus can be considered to be a simulator, but simulators also are used to train personnel; to help them understand a situation or use a process or operate some equipment. In this presentation, I will briefly discuss several issues that I feel are important to consider when using simulations or simulators for research purposes, citing examples from our experience at DCIEM with tank crew training. Though this experience has not dealt specifically with driver training, the examples do relate to important issues in the design and use of simulators for military training.

Three Domains

There are many issues that are common to the use of simulators for training research and for actual training. To be effective, any simulator needs to be designed to meet the engineering, ergonomic and educational demands of the particular task to be simulated, taught or studied. Decisions about what to model and how to model it are key questions that must be answered prior to any simulator research or development. The what determines the scope of the required simulation; this will usually have a significant impact on how the simulation is to be applied as well. Following are some examples of these issues, primarily from a researcher's perspective.

In the engineering domain, it is often taken for granted that a simulation requires the highest possible fidelity to the actual process or equipment being simulated. There are sometimes limits to this pursuit of greater fidelity, however, beyond which the present capabilities of the trainee may not require or be able to take advantage of such improvements. For example, the required resolution of a visual display may change for different training levels or tasks. In training tank gunners, the resolution required for initial training of target detection, tracking and fire control system use is much less than that required for the more difficult tasks of target recognition, i.e., friend or foe, and target identification, i.e., whether a target is an X1 tank or an X2 tank. In driver training, a similar problem involves the choice of image resolution for a visual display. Initially, novices may require only the shapes of key road signs, but later in their training both the shape and text of signs may be more important and an increase in display resolution may be required. In another example, a more complex visual display may be required to teach experienced drivers how to deal with adverse weather conditions such as rain or fog. In certain cases, exceeding the essential fidelity criteria for the level of training

may reduce the cost-effectiveness of the simulator. Determining these cases is one possible area of interest to researchers.

An effective training simulator, in any case, requires appropriate user interfaces based on sound human factors knowledge. These interfaces are required for the trainees, but also for other participants in the simulation or training scenario as well, e.g., a confederate or an instructor. There has been much research about the possible relations of trainees to training devices. There has been much less about the needs of others, e.g., those of an instructor in relation to either the student or simulator.

Information obtained from a simulator ideally should include details about the progress of a session as well as the more traditional outcome measures describing how well the trainee has performed. Deciding what level of information about the use of a simulator should be made available as feedback, and to whom, is an important issue. The needs of the student, instructor and researcher most probably differ in this regard. The instructor can use more information than the student needs, but researchers want as much information about the simulator use as possible. By designing simulators with access to all possible inputs and outputs, it would be possible to choose the appropriate feedback level for the intended audience. This, however, is seldom the case, for design or cost reasons, so knowing the intended purposes of the simulator is important.

Following is an example of the usefulness of detailed feedback from a simulator. At DCIEM, we uncovered an important procedural error being made by many of our tank gunners during an evaluation of gunnery skills using a prototype gunnery simulator. The output of the simulator was very detailed, with a record made of the timing and sequencing of all actions by the gunner. From this record, we were able to discover that two switches were being depressed in the wrong order. These switches were quite small and located on the gun controller so that the instructor had little chance to see them and the error was quite subtle in its effects. Without the detailed feedback from the simulator, an instructor would have had little chance of discovering the presence of the error. Indeed, the actual equipment had been in service for many years, with no way of knowing how long the error had been in existence.

In another development at DCIEM related to the use of feedback information from a simulator, we have recently created an "intelligent" Instructor's Aide to help gunnery instructors use the part-task gunnery simulator. This aide compares the details of the trainee's performance on the simulator to a model based on a task analysis of the expected task behaviour. It then highlights any discrepancies for the instructor. This provides additional support to the instructor, who may have been concentrating on one specific training issue and thus missed an error by the trainee in another area.

To be most effective, then, it is essential that a simulator be viewed as a complete system; one that effectively integrates the student, the simulator and any other aspects of the task or environment, including other persons, that might affect the training or research usefulness of the device.

Finally, any effective training that is to use simulations or simulators must be based on sound pedagogical theory and practice to ensure that the training system has the capability to teach the student what is required. It is not enough simply to provide a high fidelity simulation of some process or device and expect that a trainee will learn what is required by playing with it. The trainee may learn the wrong things!

As an example, in the late 1970s, the Defence Advanced Research Projects Agency (DARPA) in the US developed an interesting tank gunnery trainer based on then-new developments in video arcade game technology. Gunner-trainees using the device were rewarded with higher scores for the greater number of targets they hit. A significant problem with this device was that the gunners were not penalized for the number of shots taken to hit targets. When DCIEM obtained one of these simulators, it was obvious that training tank gunners to hit a target without regard for the number of ammunition rounds expended was not desirable, even if the trainer might improve their hand-eye coordination or knowledge of the fire control system. To prevent this type of error-learning, the DCIEM simulator was modified to remove the scoring system and to add an instructor's console to remove the control and monitoring of the gunner's training from the machine. In the realm of driver training, an analogous situation might develop if a driver were trained initially using only simulations of open highways and was then expected to be proficient at driving in a crowded city. Consequently, there should be a sound, well thought out training plan to cover the training requirements associated with simulator use.

Two Populations

It is also worth noting that training simulators often serve two populations and that the needs of one population cannot always be met with a simulator for the other. On one hand, simulators are used for the initial training of novices, who may bring only some

general skills to the task. It may even be necessary to improve some of these general skills before the teaching of specific new skills can begin. On the other hand, simulations or simulators are also used for continuation training of already learned skills or for upgrading experienced operators who must learn about new procedures or modified equipment. Whether or not to use a single simulation for both purposes and whether this will provide the most effective training for all cases are issues for researchers to address.

Evaluation and Transfer of Training

As either researcher or trainer, we are always keenly interested in the effectiveness of a simulation or simulator. The principal problem most often encountered in either realm, however, is related to the evaluation of the training or a trainer. Transfer of training is probably the most important issue in simulator research or development, or for that matter in most other types of training research. Establishing what to measure involves making clear statements about what the simulation was supposed to teach and how it was to teach it. Evaluation can be of the on-going process during use of the simulation or it can be based on some end-product evaluation measure. The latter measures are often provided through use of the operational equipment to obtain some criterion measure of learning transfer. An on-going evaluation may be based on information gathered from the use of the simulation or through testing using the actual equipment during the training period. With the present developments in simulation methods and technology, there is also the possibility that training on one basic simulator can be evaluated on another more comprehensive simulation and so on until the operational equipment must be used. Examples of this in a military context are the use of a driver's station mock-up, then a stripped down chassis, then the actual vehicle to train tank drivers in the skills needed to perform all of the procedures required to do their job. One of many problems that exist in the military setting, and that may exist in other settings as well, is that the trained driver can seldom, if ever, be tested fully in the context of the job that he or she was being trained to do. Missing from most normally available evaluation contexts, whether using a more complex simulator or perhaps a war game exercise, will be some elements of the real thing, e.g., certain stresses, anxieties or motivations, that may be important for the given training to be truly effective. Consequently, there will always be some lingering doubt about the actual extent of the transfer of that training.

Environment

Any simulation or simulator needs to be designed, built and evaluated within the overall context of the environment where the task occurs or where the equipment is to be used, to the extent that this can be done. Obviously, one can simulate a greater or lesser portion of the overall task or of the complete equipment. Decisions about the level of simulation can have important consequences for the researcher. Even adequate simulations of many small parts of a larger task will not guarantee that you will have an effective trainer when all of these bits are connected in a more comprehensive simulator.

We use part-task simulations or simulators because there is an interest in partial process learning, in the measurement of specific training effects, or in the transfer of the partial training to other simulators or to the real equipment. The only complete simulator will be the actual equipment being used in the actual manner in the actual environment. All others are, in fact, part-task trainers to a greater or lesser degree. In many military settings it is indeed unlikely that the full operational context for the training will ever be realized, leaving always some measure of doubt about the effectiveness of any trainer.

Conclusion

Without doubt, simulations and simulators are becoming more prevalent for training purposes. Although using the actual equipment is probably the most effective means of training in many circumstances, this is not always possible. Operational constraints or safety considerations may prevent the use of the actual equipment, whether that equipment is a vehicle such as a tank or a sophisticated control panel such as found in a nuclear power plant. Novices make errors while learning and their mistakes could be very costly if made using the equipment *in situ*. Simulations and simulators can help alleviate this worry, but, as can be seen, they can also introduce other problems. Be aware!

Les besoins en matière de simulateurs dans le domaine des transports terrestres

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Résumé

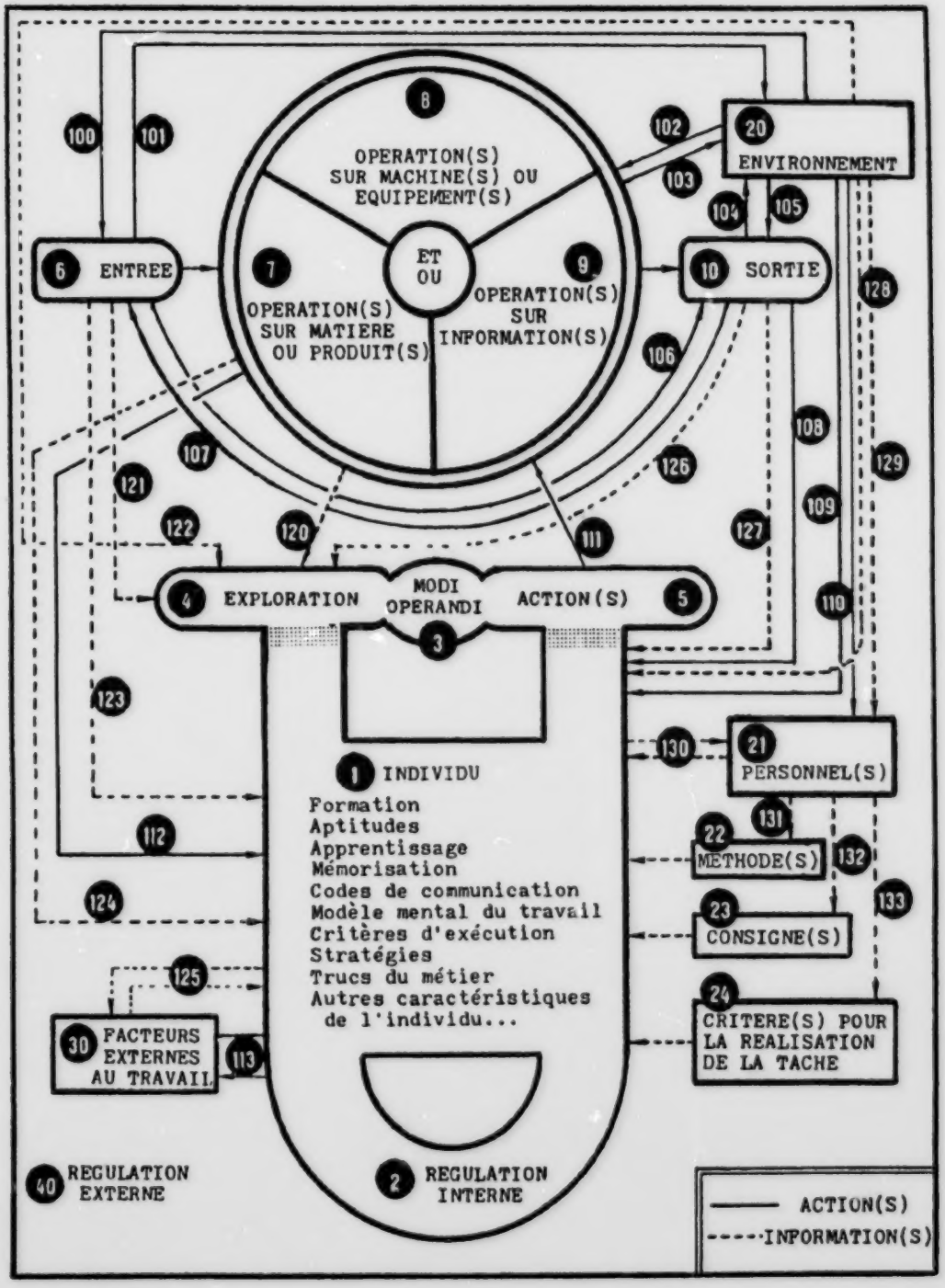
Dans ce travail, nous examinons les limites actuelles de transférabilité de l'apprentissage de simulateurs en situations réelles. Nous insistons particulièrement sur l'importance de tenir compte des modes opératoires et des automatismes qui se développent habituellement en cours d'apprentissage.

Abstract

This paper examines the current limits on the transfer of simulator learning to real situations. Special emphasis is placed on the modi operandi and automatic responses that normally develop during the learning process.

La problématique que pose la définition des exigences en ingénierie des facteurs humains d'un simulateur de poste ou de tâche est analogue à celle que soulève la modélisation des postes de travail ou des tâches. En ce sens, dans les deux cas, il s'agit d'une simplication. En conséquence, il faut donc déterminer le niveau d'acceptabilité du modèle par rapport aux objectifs spécifiques poursuivis. Il s'agit là de l'aspect le plus complexe du problème. On ne saurait envisager cette problématique sans référer aux concepts les plus fondamentaux d'un poste de travail. La figure 1 (Gilbert, 1986) illustre les principaux concepts de nature systémique caractérisant les variables à leur niveau le plus agrégé puisque dans un modèle détaillé on retrouve quelque 2 000 variables bien identifiées et non spécifiques à un poste de travail particulier (Fortin et al. 1983). De ce modèle, nous ne retiendrons ici que les éléments les moins bien connus et sans doute les plus importants. Il s'agit en l'occurence des modes opératoires et de façon toute particulière ceux qui reposent soit sur une stratégie, un algorithme ou une heuristique dont les objectifs visent soit à diminuer l'incertitude, à diminuer l'effort requis ou encore à améliorer l'efficacité du système. On comprend facilement que de tels modes opératoires viennent modifier parfois de façon très substantielle les exigences apparentes du poste de travail. Nous rappellerons donc ici la distinction nette qui existe entre modes opératoires et méthode de travail. Dans un poste de travail, les méthodes constituent un ensemble réduit de règles imposées, suggérées ou parfois absentes et qui émane du concepteur ou de l'exploitant en vue de régir les activités de l'opérateur. Les modes opératoires eux représentent la façon dont s'y prend réellement l'opérateur pour atteindre les objectifs établis pour le poste.

Du point de vue conceptuel, les modes opératoires sont identifiés aux programmes et donc aux codes générés par le système nerveux dont l'exécution se traduit par la réalisation des activités de l'opérateur. En ce sens, ils sont homologues aux codes utilisés par un robot. Il est évident que nous n'avons pas encore accès directement ni aux codes, ni au langage qu'utilise le système nerveux. Cependant, l'analyse des activités du travail nous permet souvent de déceler les stratégies et les trucs que comportent certains modes opératoires. Nous qualifions donc ces modes opératoires comme critiques ou remarquables. L'analyse et surtout l'interprétation des résultats de l'analyse du travail nous amène à considérer sur un même pied que les modes opératoires, les divers automatismes que développent les opérateurs. La figure 2 montre le cheminement à suivre dans l'évaluation de la charge de travail et la nécessité d'évaluer les automatismes. Le lecteur trouvera ailleurs (Gilbert, 1983) des exemples qui démontrent l'importance et la nécessité d'identifier les modes opératoires remarquables et les automatismes. Sans ignorer la multitude des connaissances nécessaires dans tout problème de modélisation et donc de simulation, il reste que les modes opératoires remarquables et les automatismes représentent l'assise non plus de la description d'un système ou même de la description de son fonctionnement mais bien celui de la compréhension de son fonctionnement. Nous rappelerons ici l'importante distinction entre opérateurs novices et opérateurs expérimentés. En effet, les modes opératoires remarquables ainsi que les automatismes n'existent pas



D'après R. Gilbert

Figure 1

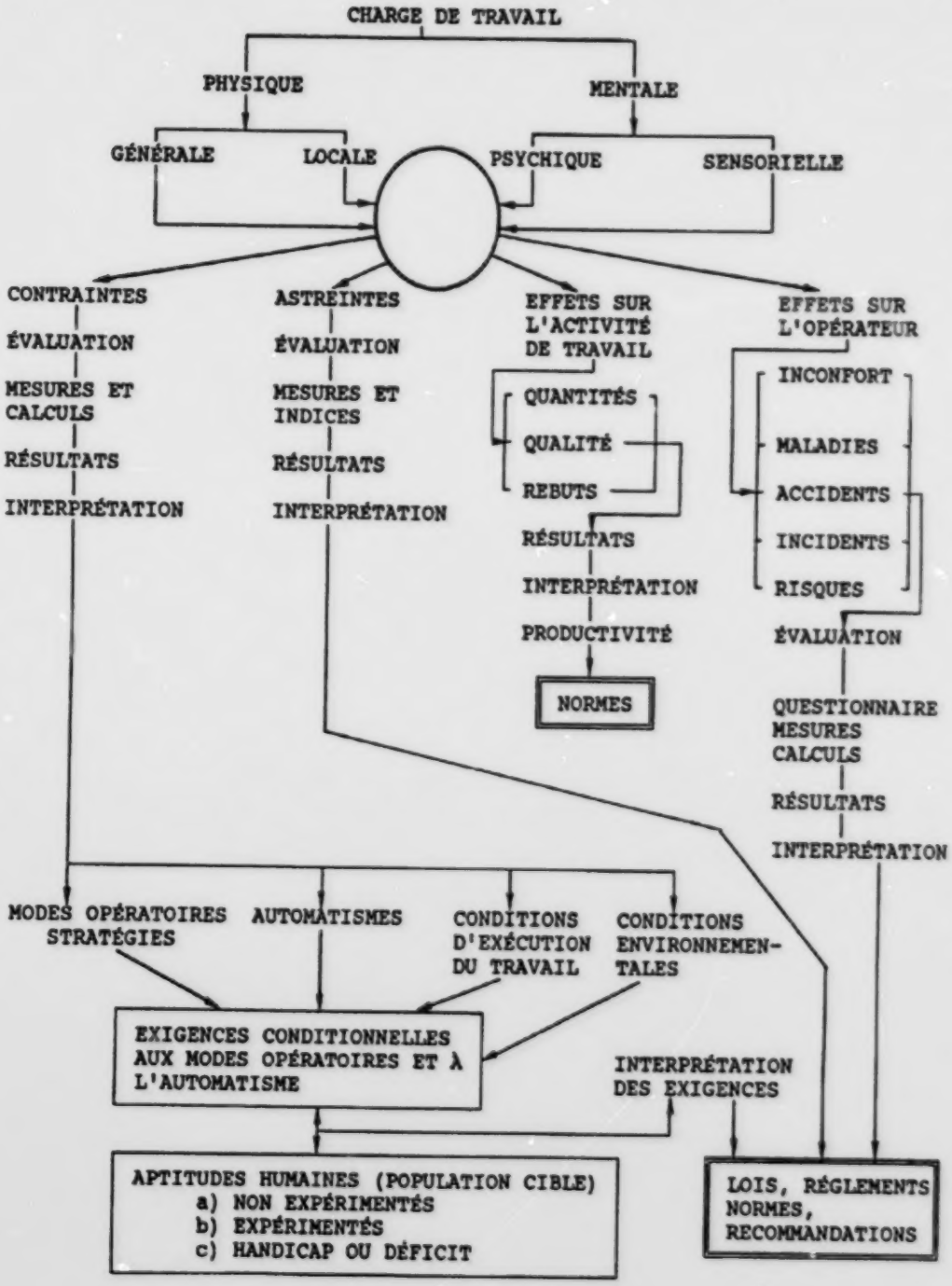

CHARGE DE TRAVAIL
PHYSIQUE
MENTALE
GÉNÉRALE
LOCALE
PSYCHIQUE
SENSORIELLE
CONTRAINTES
ÉVALUATION
MESURES ET CALCULS
RÉSULTATS
INTERPRÉTATION
ASTREINTES
ÉVALUATION
MESURES ET INDICES
RÉSULTATS
INTERPRÉTATION
EFFETS SUR L'ACTIVITÉ DE TRAVAIL
QUANTITÉS
QUALITÉ
REBUTS
RÉSULTATS
INTERPRÉTATION
PRODUCTIVITÉ
NORMES
EFFETS SUR L'OPÉRATEUR
INCONFORT
MALADIES
ACCIDENTS
INCIDENTS
RISQUES
ÉVALUATION
QUESTIONNAIRE MESURES CALCULS
RÉSULTATS
INTERPRÉTATION
MODES OPÉRATOIRES STRATÉGIES
AUTOMATISMES
CONDITIONS D'EXÉCUTION DU TRAVAIL
CONDITIONS ENVIRONNEMENTALES
EXIGENCES CONDITIONNELLES AUX MODES OPÉRATOIRES ET À L'AUTOMATISME
INTERPRÉTATION DES EXIGENCES
APTITUDES HUMAINES (POPULATION CIBLE)
a) NON EXPÉRIMENTÉS
b) EXPÉRIMENTÉS
c) HANDICAP OU DÉFICIT
LOIS, RÉGLEMENTS NORMES, RECOMMANDATIONS

Figure 2

chez le novice, ils se découvrent ou se développent par l'apprentissage. Ce phénomène est d'autant plus important que la simulation que l'on désire réaliser vise principalement l'entraînement des nouveaux candidats. Comme il s'agit du cas le plus courant en simulation, il devient capital d'apporter la plus grande attention aux phénomènes de transfert positifs et négatifs d'apprentissage du simulateur au poste réel. Les subtilités de ce transfert d'apprentissage peuvent constituer des pièges pour le concepteur du simulateur. Si l'analyse des modes opératoires et des automatismes apparaît si importante pour le développement et la validation d'un simulateur, il arrive souvent que nous ayons affaire à un nouveau poste pour lequel on ne peut donc appliquer une procédure analytique systématique. Dans ce cas, deux possibilités s'offrent au concepteur, l'étude de postes similaires s'ils existent et l'application de la méthode des scénarios au nouveau design en vue d'élaborer en particulier l'éventail le plus complet et le plus précis des « modes opératoires possibles » et les automatismes les plus plausibles.

Mis à part ces considérations, il reste encore deux autres problèmes non résolus en ce qui concerne la conception et le développement de simulateurs. Le premier concerne les états d'un système tels la visualisation de scènes, la lecture d'informations ou la perception de signaux qui témoignent de situations critiques. En effet, si l'on peut simuler correctement ces variables, i.e. de façon identique à la réalité, il n'en demeure pas moins une insuffisance grave qui réside dans l'interprétation irréaliste de ces situations par l'opérateur en poste au simulateur.

De fait, les analyses que nous avons réalisées dans diverses études concernant le métro de Montréal en particulier démontrent que le niveau de stress ou de vigilance n'atteint jamais en simulation ceux de la réalité. Nous avons noté les mêmes phénomènes chez les contrôleurs aériens. Comme le rapporte Wilde, même si l'on arrive par des « moyens artificiels » à créer un stress équivalent à celui de la réalité dans un cas critique, la vigilance résultante se partage nécessairement entre la tâche réelle et la tâche artificielle parallèle.

Le deuxième a trait au « feedback » sensoriel qui provient du véhicule et de ses commandes. À ce sujet, nous rappelons les difficultés qu'éprouvent les novices à contrôler l'accélération et plus spécifiquement le freinage de métro en conduite manuelle évidemment. Cette commande, appelée manipulateur, s'opère par une rotation horaire (freinage) et antihoraire (accélération). La maîtrise de cette commande requiert un apprentissage d'automatisme où plusieurs sens (vision, équilibre, tactilité) sont utilisés. Les limitations du simulateur de conduite du métro qui est spatialement fixe ne peut tout au plus que permettre de construire le stéréotype (acquis) du sens de rotation pour le freinage et l'accélération. Ce simulateur, aujourd'hui complètement abandonné a été avantageusement remplacé par un vrai train sur une voie dédiée à la formation. Comme le lecteur a pu le déduire, le présent exposé se veut une critique constructive des fondements et des concepts liés aux simulateurs. Le but poursuivi étant d'attirer l'attention sur quelques limitations que comportent les simulateurs et qui forcément dépendent des objectifs que l'on désire atteindre par de tels moyens.

Ainsi, si l'on ne peut arriver à valider un simulateur pour des objectifs fixés à priori, compte tenu des subtilités émanant des modes opératoires et modifiant les exigences du poste, il serait possible de redéfinir des hypothèses moins gourmandes lesquelles auraient davantage de chance d'être validées et cela sans nécessairement devoir apporter des améliorations au simulateur. Quant à l'utilisation des simulateurs pour l'étude du comportement humain, il est peu probable que les résultats puissent être facilement transférables dans la réalité. À ce sujet, on connaît plusieurs de ces résultats de laboratoire dont le seul intérêt est celui de faciliter la formulation d'hypothèse qui nécessitent une validation en situation réelle.

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Some Simulation Solutions for Arctic Marine Navigation

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Abstract

In this paper, we consider the simulation techniques that could be used to address ergonomics problems in Arctic marine navigation. We examine five areas in detail: 1) remote sensing, 2) piloted ship controllability and manoeuvring strategies, 3) bridge design, 4) bridge organization and communications, 5) ports and harbours. We suggest that remote sensing problems are best addressed in laboratory based studies which combine image processing techniques with psychometric evaluations of operator preference and ice detection performance; ship controllability, manoeuvring strategies, bridge organization and communication, and port and harbour design would benefit from real-time simulation; bridge design, and some aspects of bridge crew organization and communications are best studied with the use of mock-ups.

Note: *Paper not available for publication. See "Ergonomic Considerations in Arctic Marine Navigation" on page 37 for a discussion on this subject.*

Résumé

Les auteurs traitent des techniques de simulation permettant de trouver des solutions ergonomiques en matière de navigation maritime dans l'Arctique. Ils ont approfondi les cinq secteurs suivants : 1) télédétection, 2) stabilité et techniques de pilotage des navires, 3) étude de passerelles de navigation, 4) aménagement des passerelles et communications, et 5) ports. Les auteurs avancent que le secteur de la télédétection devrait être étudié dans des laboratoires où les techniques de synthèse des images peuvent être associées à des analyses psychométriques des performances des opérateurs dans la détection des glaces flottantes et de leurs préférences; que les secteurs de la stabilité et des techniques de pilotage des navires, de l'aménagement des passerelles et communications ainsi que celui des ports pourraient tirer parti des possibilités de simulation en temps réel; et que l'étude des passerelles de navigation et de certains aspects de leur aménagement et des communications se ferait avantageusement à l'aide de maquettes appropriées.

Note : *Cette communication n'est pas disponible pour publication. Voir « Ergonomic Considerations in Arctic Marine Navigation » en page 37 pour un débat sur ce sujet.*

SESSION 4

Training and Assessment Considerations

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ATELIER 4

Apprentissage et évaluation

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Certaines réflexions relevées de la formation et évaluation dans le contrôle aérien

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Résumé

Le contrôle aérien est fourni à partir des tours de contrôle pour les aéroports et des centres de contrôle épartis à travers le pays pour la circulation entre les aéroports. La formation du contrôleur aérien comprend un cours de base donné à l'école nationale de Cornwall et suivi de cours spécialisés dans les régions. Les cours comprennent généralement la théorie suivie de son application en simulation. La simulation joue un rôle primordial dans la formation pour le contrôle IFR et augmentera encore au cours des années à venir.

Abstract

Air traffic is controlled from control towers at airports and control centres spread out across the country. Air traffic controller training includes a basic course at the national school in Cornwall, followed by specialized courses in the regions. Courses generally consist of theory followed by practical training through simulation. Simulation plays a vital role in training for IFR control, and will become increasingly important over the coming years.

1. Introduction

La formation du contrôleur aérien est longue et ardue. Présentement, il y a un manque de quelque 300 contrôleurs. Afin d'y remédier, notre programme de formation fonctionne à plein régime. Notre école nationale à Cornwall offre 13 cours de 24 étudiants chacun pour un total de 312 débutants par année. Vous pensez sans doute qu'un manque de 300 contrôleurs se comble vite avec 312 étudiants débutant chaque année, mais avec un taux de réussite d'à peine 25 p. 100, je vous assure que nous sommes loin d'avoir trouvé la formule magique. Néanmoins, je vais partager avec vous quelques observations sur notre expérience acquise au fil des dernières années.

2. Aperçu du contrôle aérien

Avant d'aborder la formation du contrôleur aérien, je crois que quelques minutes sont nécessaires pour vous expliquer ce qu'est le contrôle aérien.

Comme beaucoup d'autres professionnels, tels le chirurgien, le pilote et bien d'autres, les erreurs ne nous sont pas permises. Le contrôleur aérien doit viser à la perfection même si l'on sait qu'une telle ambition est utopique. Des erreurs se glissent toujours mais le système et les procédures de travail étant munis de certaines marges dites de sécurité, permettent de pallier, dans la mesure du possible, aux catastrophes majeures.

Le contrôle aérien fournit plus d'un type de service mais je vais me limiter à deux de ceux-ci: le contrôle d'aéroport et le contrôle de vol aux instruments plus communément connu sous son acronyme anglais IFR qui veut dire: « Instrument Flight Rules ». Le contrôle d'aéroport est fourni par 56 tours au pays et environ 800 contrôleurs y travaillent. Ceux-ci sont responsables pour toute la circulation évoluant sur l'aire de manoeuvre de l'aéroport et pour les aéronefs évoluant dans la zone de contrôle qui comprend un espace aérien dont la superficie varie de 3 à 10 milles de rayon. Le contrôleur est responsable des atterrissages et des décollages ainsi que des aéronefs qui volent dans l'espace aérien.

Le contrôle IFR moins bien connu que le contrôle d'aéroport, est fourni par 7 centres de contrôle situés dans diverses régions du pays. Plus de 900 contrôleurs y contrôlent l'espace aérien de tout le pays ainsi que la moitié de l'océan Atlantique. Un vol qui décolle de Vancouver à destination de Londres par exemple, est sous le contrôle canadien jusqu'à mi-chemin au-dessus de l'Atlantique. C'est un contrôle plus complexe que celui des tours car le contrôleur assume la responsabilité de maintenir un minimum d'espacement entre chaque aéronef. La séparation se fait principalement à l'aide de radar mais dans les régions où la couverture radar manque, nous utilisons des procédures basées sur un espacement vertical, horizontal ou longitudinal.

Les tâches diffèrent d'un poste de travail à l'autre. Le contrôleur qui s'occupe des arrivées et des départs, comme à Dorval et à Toronto, n'accomplit pas les mêmes tâches que le contrôleur responsable pour les aéronefs qui survolent l'Atlantique.

3. Analyse des besoins de formation

On ne peut donc pas s'attendre qu'un cours puisse contenir toute la théorie et les exercices de pratique pour tous les postes de travail. L'approche que nous suivons pour nous assurer que les étudiants reçoivent une formation adéquate par rapport aux exigences du travail, sans pour autant lui faire subir un cours comprenant tout sur le contrôle aérien, est « l'Approche systémique à la formation ».

Celle-ci comprend une analyse des tâches du contrôleur aérien qui aide à déterminer les objectifs de la formation. Une fois les objectifs déterminés, l'étape suivante est l'élaboration de cours pour rencontrer ces objectifs. C'est aussi à cette étape que les critères d'évaluation sont conçus.

Vu la diversité des tâches, plus d'un cours est requis pour rencontrer les besoins de formation pour les différents postes. Nous avons réparti nos cours de la façon suivante: cours de base à l'école nationale d'une durée de 104 jours pour le contrôle IFR et d'aéroport avec 18 jours ajoutés pour la simulation en contrôle d'aéroport; ensuite, dans les régions, des cours spécialisés pour l'endroit en question suivi de formation en milieu de travail jusqu'à certification.

4. Cours de base

Comme mentionné auparavant notre cours de base est présenté à notre école nationale de Cornwall. Il comprend théorie et simulation. La théorie regroupe divers sujets tels météorologie, théorie de vol, principes du contrôle aérien, règlements de l'air, etc. La simulation comprend la moitié de notre cours de base et sert à étoffer les théories apprises. Nous utilisons trois types de simulation: la simulation du contrôle procédurier, la simulation du contrôle radar et la simulation du contrôle d'aéroport. Nous obtenons un succès certain quant à la présentation de la théorie en classe. Notre taux de réussite est de plus de 95 p. 100. En simulation toutefois notre succès n'est pas aussi reluisant, notre taux de réussite ne se chiffre qu'à 60 p. 100. Les cas d'échecs ont lieu à ce stade. Un grand nombre de nos étudiants rencontrent des difficultés au moment de la transition entre la théorie offerte en classe et son application en simulation. Nous sommes présentement à restructurer le cours afin de faciliter cette transition, mais ce n'est pas chose facile lorsque nous ne pouvons pas nous permettre d'arrêter ou même de ralentir le processus de formation. Une autre des mesures prévues pour faciliter la transition entre la théorie et la simulation sera l'introduction du projet de Johanne Bernier qui est la « Formation assistée par ordinateur » (FAO). Cette approche permettra à l'étudiant d'apprendre selon son rythme et de répéter aussi souvent qu'il le veut les leçons et les exercices du cours. Nous croyons que la FAO est le moyen idéal de combler l'écart entre la théorie et sa mise en application en simulation.

5. Formation régionale

La formation régionale commence une fois que les étudiants ont réussi le cours de base à l'école nationale. Cette nouvelle étape donne lieu à la formation spécialisée. Les stagiaires choisis pour le contrôle d'aéroport procèdent directement aux tours de contrôle où un cours théorique spécialisé sur l'aéroport assigné leur est donné. Ce cours les familiarise avec la disposition des pistes et des voies de circulation, les diverses compagnies aériennes qui opèrent à l'aéroport, la géographie immédiate, le genre de contrôle fourni par la tour, l'équipement utilisé, les nombreux types d'avions qui y volent, etc. Ce cours peut varier d'une journée à 20 jours dépendamment de l'importance de l'aéroport et de la complexité des opérations. Puis, vient la formation en milieu de travail qui commence avec le travail administratif passant au contrôle au sol pour ensuite couvrir le contrôle des aéronefs en vol. Cette période de formation se fait sans simulation et le temps requis pour atteindre le niveau de qualification varie selon le stagiaire, l'unité et la période de l'année.

En ce qui a trait à la formation des contrôleurs IFR, ces derniers se dirigent à l'école régionale où ils entreprennent un cours de 4 à 5 mois comprenant de la théorie et de la simulation spécifiques aux secteurs sur lesquels ils travailleront. Ils seront guidés par des instructeurs qualifiés qui sont aussi des contrôleurs chevronnés sur ces secteurs. Ceci nous assure que, les exercices utilisés en simulation reproduisent aussi fidèlement que possible, les situations de travail que les stagiaires rencontreront dans le milieu opérationnel et que les explications fournies par les instructeurs sont pertinentes.

Une fois qu'ils ont réussi le cours, les stagiaires quittent l'école pour se rendre à l'unité de contrôle où ils sont assignés à des contrôleurs-formateurs pour le stage de formation en milieu de travail. Ce stage peut durer de 4 à 12 mois dépendamment de l'unité et de la période de l'année.

Les problèmes majeurs de la formation en milieu de travail sont nombreux.

i. Le stagiaire doit être capable de s'ajuster au rythme de la charge de travail. Au début de son stage, le stagiaire ne peut pas rencontrer les exigences du travail. Il doit donc se contenter d'apprendre en observant son instructeur travailler. Vers la fin de sa formation, lorsqu'il est prêt à prendre les commandes lors de périodes de circulation lourde, c'est souvent l'inverse qui se produit. Parce que les périodes de lourd trafic ne sont pas toujours régulières et vu les quarts de travail qui l'obligent à travailler à des moments moins mouvementés, le stagiaire peut passer quelques semaines avant de revivre pareille difficulté, ce qui a pour effet de prolonger sa période de formation.

ii. Pendant sa formation en milieu de travail, le stagiaire vit une situation réelle, il contrôle de vrais avions avec passagers. Son instructeur doit le surveiller en tout temps et être prêt à prendre la relève au moment où le stagiaire semble en difficulté ou qu'il est dépassé par le nombre d'avions.

iii. La tâche première de l'instructeur est de contrôler, et la formation passe en second. En périodes occupées, il n'a pas le temps d'expliquer en détail toutes les manoeuvres du contrôle alors le stagiaire doit apprendre en observant le travail accomplit par son instructeur.

iv. Le service que le stagiaire fournit est loin d'être aussi efficace que celui d'un contrôleur chevronné. Nos clients, les pilotes, sont donc moins bien servis.

Pour corriger ces problèmes, certaines mesures sont en voie d'implantation. Les exercices de simulation seront plus approfondis une fois que toutes nos écoles régionales seront munies de meilleur équipement. Dans les unités où la charge de travail est trop lourde, nous avons entrepris une redistribution du travail en créant de nouveaux secteurs.

Nous avons aussi implanté, cette année, la possibilité d'une qualification partielle sur certains secteurs pour faciliter la formation. Le stagiaire, qualifié sur deux secteurs, a la permission de travailler seul pour une période de temps. Ceci lui permet d'acquérir de l'expérience et de l'assurance avant d'entreprendre la formation sur les autres secteurs de la spécialité.

Lorsque l'instructeur, après consultation avec le surveillant de la formation, considère que le stagiaire est prêt à travailler seul, ce dernier est observé par le surveillant pour une période de temps. Si satisfait du travail fourni par le stagiaire, le surveillant le recommande pour qualification. Le stagiaire devient donc un contrôleur qualifié pour cette unité et finalement travaille de façon autonome.

Le fait d'être qualifié ne veut pas dire que la formation du contrôleur est terminée. Ce dernier doit aussi suivre un cours de recyclage chaque année. Si un nouveau système automatisé est introduit à l'unité comme notre nouveau système radar RAMP, un autre cours spécialisé sur l'utilisation de l'équipement devient obligatoire. Il en va de même lorsqu'un surveillant identifie un manque grave dans l'exécution des tâches d'un contrôleur; ce dernier est relevé de ses fonctions et, si nécessaire, doit suivre un cours correctif. Même un contrôleur qualifié qui change d'unité, ou encore un contrôleur d'aéroport qui veut devenir contrôleur IFR ou vice versa, doit suivre un cours et un stage de formation pour se qualifier.

6. Utilisation de simulateurs

Il est inconcevable pour nous d'essayer de former des contrôleurs aériens sans l'utilisation de simulateurs. Même lorsque j'étais en stage de formation pour devenir contrôleur, il y a plus de 20 ans, nous pratiquions sur des simulateurs. Aujourd'hui, notre équipement est beaucoup plus perfectionné, mais nous exigeons aussi plus de nos étudiants.

Nous avons tout dernièrement ajouté un nouveau simulateur radar dans toutes nos écoles. Ce système ressemble à notre système radar opérationnel et nous permet de former nos étudiants avec encore plus de réalisme qu'auparavant. Malheureusement, nous n'avons pas tous les autres systèmes nécessaires pour reproduire exactement et en totalité l'environnement opérationnel. D'ici quelques mois nous devrions acquérir un système de communication qui ressemblera de très près à notre système opérationnel. Nous avons aussi l'intention d'ajouter d'autres systèmes pour nous rapprocher, autant que possible, de l'opération dans nos unités de contrôle. Nous désirons éventuellement pouvoir former nos étudiants presqu'en entier à l'aide de nos simulateurs. Nous n'atteindrons jamais le niveau de sophistication des simulateurs d'avions, mais nous aimerions pouvoir former nos contrôleurs au point où leur habilité d'accomplir le travail ne soit plus mise en doute et que la transition du contrôle fictif au contrôle réel soit assurée.

7. Conclusion

En tant que responsable de la formation, cette dernière m'apparaît comme essentielle et devient de plus en plus capitale. Une analyse des tâches est requise pour s'assurer que la formation est économiquement rentable et qu'elle prépare adéquatement les personnes à accomplir leur travail. Aussi, autant que possible il est nécessaire, dans les premières étapes de la formation, d'ajuster l'apprentissage selon la rapidité des étudiants et d'éviter de les plonger subitement dans le rythme accéléré des milieux opérationnels. Et finalement reconnaître que la formation est un processus sans fin tout au long de notre carrière. Les changements technologiques sont si rapides que nos connaissances et nos méthodes de travail d'aujourd'hui s'avéreront désuètes demain.

The Benefits of Simulators in Locomotive Engineer Training

Donald J. Manconi
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Good morning ladies and gentleman. I am pleased to have the opportunity to talk to you today on one of my favorite subjects – Locomotive Engineer Training.

When I first started with CP Rail in 1954, firemen or otherwise called engineer helpers required a minimum of three years of on-the-job training before they could write the Locomotive Engineer Mechanical Examinations. Once they passed the required examinations and demonstrated to a Road Foreman that they could operate a train safely over their respective territories only then would they be qualified as a Locomotive Engineer.

The increase in freight traffic and the jump from steam to diesel power created a demand for more qualified locomotive engineers and to be qualified in a shorter period of time.

Of all the vital knowledge the locomotive engineer must possess to successfully operate freight trains, a working knowledge of the air brake system and its functions ranks at the top of the list to enable him or her to operate in a safe and competent manner.

In order for a locomotive engineer to meet these standards and to satisfy the increased demand for more locomotive engineers, CP Rail developed a Locomotive Engineer Training Program in the early 70s.

The program consisted of Rules and Mechanical classroom instructions, followed by several months of on-the-job training. Depending on the size of the territory a locomotive engineer could be qualified in less than one year.

In 1970, CP Rail leased a Train Dynamics Analyzer for the purpose of developing train handling techniques for various types of trains, to determine the optimal location of mid train power for our Remote Control Equipped Trains in coal service in Western Canada and also to assist in our derailment investigations.

The analyzer used at that time was a computer-operated system designed to simulate train operation, display slack action throughout the train and air brake functions over any given portion of CP Rail's main track.

The system was equipped with a graphic display monitor which displays the profile of the territory; draft and buff forces are graphically displayed along with air brake cylinder pressure throughout the train.

In 1975, CP Rail leased a second TDA and placed it into a mobile vehicle. The TDA travelled coast to coast and engineers across the country had an opportunity to simulate operation of trains over their respective territories to determine the best train handling method for specific trains.

In 1979, when the cost of fuel outstripped the cost of wages CP Rail leased an additional TDA and placed it into a mobile vehicle as well. A Fuel Conservation Training Program was developed using TDA to demonstrate specific train handling procedures.

From 1980 to 1989 the two mobile units travelled across the country. Every engineer was given an opportunity to run various types of trains on the analyzer to see for themselves the benefits of controlling freight trains by throttle modulation and use of dynamic braking instead of power braking, which is the use of excessive power to overcome the train brakes to control slack and/or reduce train speed.

I am proud to say that CP Rail has been successful in reducing its fuel cost by 50 million dollars a year since the Fuel Conservation Program was initiated, in which the locomotive engineer played a major role.

By the end of 1989, both mobile units were taken out of service and the older TDAs were replaced with the newer generation of Train Dynamic Analyzer.

One TDA 4000 with two operating stations was placed in the Locomotive Engineer Training Centre in Montreal and the other was placed in Vancouver and scheduled to be relocated in the Locomotive Engineer Training Centre in Calgary sometime during the month of November of this year.

With the two operating stations on the same system we have the capability of operating two separate trains, over the same territory, in the same manner and demonstrate the dynamic forces within the train when trains are marshalled differently, such as loaded cars ahead of empty cars on one train versus loaded cars behind empty cars on the other train.

We also use the two operating stations when we want to demonstrate fuel savings when the same train is operating over the same territory but this time under different train handling methods.

Another use of the two operating stations is when we need to compare the in-train forces when the locomotives are placed in different locations within the train.

With the introduction of the train simulator to the Locomotive Engineer Training Program, locomotive engineer trainees will receive at least eight hours of simulator time during the initial two weeks of mechanical class room instruction. This added training will provide the trainee with a better understanding of the air brake system and dynamic forces within the train and will underline the importance of proper train handling procedures especially when it comes to saving fuel.

The eight hours on the simulation should provide the trainee with the skill required to be in a position to take over the controls of a train under the guidance of a qualified locomotive engineer instructor, at the start of the on-the-job training portion of the program.

The simulators are available to qualified locomotive engineers and trainees at any time they wish to experiment with various types of trains and to operate trains under certain conditions that they may never have an opportunity to encounter during their regular tour of duty.

Over the last 10 years, freight trains have increased in size and weight and have placed a greater demand on the locomotive engineer and are less forgiving of even small mistakes in train handling. The next decade promises to make even more demands of the locomotive engineer's knowledge and skills. New technology will bring with it more advanced locomotive brake systems, new freight equipment, freight car brake systems, micro-processor controlled locomotives and Automatic Train Control System. Therefore, training technology must keep pace with time.

At CP Rail, as well as adapting to changes in technology, air brake and train handling training in our Engineer Training Program has also adapted to change.

The new generation of locomotive training simulators are perhaps the most valuable training tool ever introduced to engineer training. They are available from the lower end graphics – only locomotive simulators – to the top of the line full replica locomotive simulator with complete locomotive cab and motion base.

The new Locomotive Engineer Training simulator is a simulator training system that was developed to provide the realism that previously could only be found aboard a locomotive. Plus the LETS uses the same software as the TDA 4000 and a modulator approach for option selection. Using LETS modular option selection we can literally pick the training system to fit our own needs and budget. We have the benefit of selecting the options we desire such as locomotive cab, motion base, laser disc video, digital sound and more.

Since CP Rail introduced the TDA in 1975 to locomotive engineers and introduced the TDA into locomotive engineer training program in 1989, train handling has improved and CP Rail's operating costs have been reduced due to a reduction in fuel cost, lading damage, train and equipment damage. Furthermore locomotive engineers in some areas are now qualified in less than 6 months.

The train dynamics analyzer located in headquarters in Montreal plays a major role in rule making, derailment investigation, equipment design, research and is also involved in the development of a braking algorithm for future Automatic Train Control System.

Locomotive engineers at CP Rail are required to operate trains over some of the most difficult terrain in the country and we are proud to say that the train dynamics analyzer has helped us in maintaining the best safety record of any class-one railroad in North America. I hope the presentation has helped you and I thank you for your attentiveness.

Training to Meet the 1978 STCW Requirements

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1. Introduction

The International Maritime Organization held the Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) from June 14 to July 7, 1978 in London, England. The intent of the Convention was to promote the safety of life at sea and the protection of the marine environment by establishing in common agreement international standards of training, certification and watchkeeping for seafarers. Canada, as a member of the IMO, has ratified this Convention and is in the process of implementing its 21 Resolutions.

This paper will discuss the impact on marine simulation training of one major feature of the convention; the requirement for Canada to establish a Continued Proficiency Endorsement program for Deck and Engine Room Certificates of Competency. It will discuss the following training issues:

- Requirements of Future Simulators
- Revision of Training Objectives; and
- Performance Measurement Instruments.

2. International Maritime Organization

2.1 Description of IMO

IMO is a specialized agency related to the United Nations. It was originally created by the UN Maritime Conference in Geneva in 1948 as the Intergovernmental Maritime Consultative Organization (IMCO). It was renamed the International Maritime Organization under a revised Convention in 1984[1]. The activities of the Organization are concentrated principally on measures to promote effective global implementation of standards and regulations for the improvement of maritime safety and the prevention and control of marine pollution from ships. This is achieved through the convening of international conferences and through drafting international agreements and conventions. Once a member country ratifies a convention, regulations contained within it are usually incorporated into appropriate national statutes.

Membership is approximately 125 nations. The Organization performs depository and related functions for the conventions drawn up by its various Committees. (See Appendix 1 for an extract from the IMO Convention detailing the purposes of the organization.)

2.2 Standards of Training, Certification and Watchkeeping Convention

The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW) was held by IMO in 1978. Its purpose was to promote the safety of life and property at sea and the protection of the marine environment by establishing standards of training, certification and watchkeeping.

The STCW Convention came into effect internationally in 1984. Countries which had not yet ratified the Convention (of which Canada was one of many) found that their Certificates of Competency issued after that date did not enjoy the normal privileges on foreign-going voyages to countries which had ratified the Convention. It was necessary to devise and incorporate a temporary system of Letters of Compliance.

Canada could not ratify the STCW Convention until amendments were made to the Canada Shipping Act. The amending of the Act through Bill C-39 was assented to on March 26, 1987. This permitted the necessary regulatory changes which would allow Canada to ratify the Convention. Canada has signed the Convention; it became effective on February 6, 1988. The appropriate regulations have been or are in the process of being drafted by the Transport Canada Legal Branch. At this time, it is intended for them to be published in the

[1] *Convention on the International Maritime Organization, IMO, London, 1984.*

Gazette in the First Quarter of 1991. These regulations will have a two year phasing in period and the STCW Convention will be entirely in force in Canada by February 6, 1993.

3. Impact on the Canadian Industry

3.1 Continued Proficiency Requirements

Regulation II/5 of the STCW Convention imposes a mandatory requirement for ensuring the continued proficiency and the updating of knowledge of certified mariners. As a consequence of this regulation, mariners will be required to have their certificates endorsed to the effect that they have maintained their currency. One method of obtaining this endorsement will be through successfully completing a course or courses set by the national administration.

3.1.1 Deck Officers

In Canada, Deck Officers will be required to successfully complete two courses every five years for a Continued Proficiency Endorsement: a Simulated Electronic Navigation (SEN) and a Marine Emergency Duties (MED) course of the appropriate level for their certificate.

The requirement to attend Simulated Electronic Navigation (SEN) courses will have a significant impact on the numbers of such courses that will have to be offered in Canada. At present, there are two levels of the Simulated Electronic Navigation (SEN) course: SEN I for officers holding certificates of the watchkeeping level and SEN II for officers holding certificates qualifying them for command level positions. Both courses now include simulated training in Automated Radar Plotting Aids (ARPA).

3.1.2 Engineering Officers

In Canada, Engineering Officers will be required to successfully complete two courses every five years for a Continued Proficiency Endorsement: a Diesel Control Room & Systems and a Marine Emergency Duties (MED) course of the appropriate level for their certificate.

The Diesel Control Room & Systems Course will be given on an engine control room simulator. There will also be two levels for this course: a watchkeeping and a senior engineer (plant manager) level. The watchkeeping level simulation will include start-up from a cold ship, monitoring of steady state steaming, and emergency drills. The plant management simulations will include diagnostic routines, and the planning and scheduling of preventative maintenance. In addition, simulation training in energy management is also being planned for senior engineers.

3.1.3 Annual Training Requirements

The following tables are based on present examinations for Certificates of Competency (Canadian Coast Guard Ship Safety Branch).

DECK	**SEN I**	**SEN II/ARPA**
	450	250
Engineering	**Watchkeeping**	**Plant Manager**
	about 650 per year	650 1991 620 1992 declining to about 500 per year by 1998

3.1.4 Training Issues Resulting From STCW

Simulator Requirements

The purpose of the Continued Proficiency Endorsement is to ensure that the mariners in charge of the conduct of vessels at sea are competent to use the state of the art equipment and systems. Therefore, the simulators of the future must be able to incorporate new technologies as they arise.

In the past, marine simulators were designed to deliver a high degree of fidelity with respect to the shipboard environment. They were built with existing equipment, with fixed displays and control systems. These simulators were hardware driven.

Simulators of the future will have to be designed in such a manner that they will be easily, and economically, modified to reflect changing technologies. They must be built to accept the installation of new navigation and control systems. This means that the interface between the simulation generator and the shipboard components must be software driven. In addition, the simulator should be designed so that various bridge layouts may be configured for varying candidate populations.

Training Objectives

The training objectives for the Simulated Electronic Navigation (SEN) courses have been derived through joint consultation with the Canadian Coast Guard Ship Safety Branch, the shipping industry associations and the nautical schools in Canada. These objectives are detailed in the CCG Ship Safety Branch document, "Simulated Electronic Navigation Courses," (TP 4958).

The training objectives will require periodic revision due to the rapid state of technological change. The inclusion of material covering the use of Automated Radar Plotting Aids (ARPA) is a recent example of the need to revise these objectives on a regular basis. The developing technologies around electronic charting will have to be addressed in the near future.

Equally important, from the training point of view, is that the training objectives be written in a measurable format. That is to say that the performance described in the training objective should be stated in terms that allow the trainer to monitor the performance and measure the candidate's success.

Figure 1 illustrates the "Training Triangle." A Training Needs Analysis of the job of the ship's officer should be the source of the training objectives. Training for the tasks is then based on the performance described in the training objectives. Finally, at the completion of training, the performance of the candidate must be tested or evaluated. If training matches the needs indicated during the needs analysis, the candidate should be adequately equipped to perform the tasks required when he returns to the job. Therefore, it is important that the currency of the training objectives be constantly monitored by the national certifying authorities, to maintain congruency between training and the actual job.

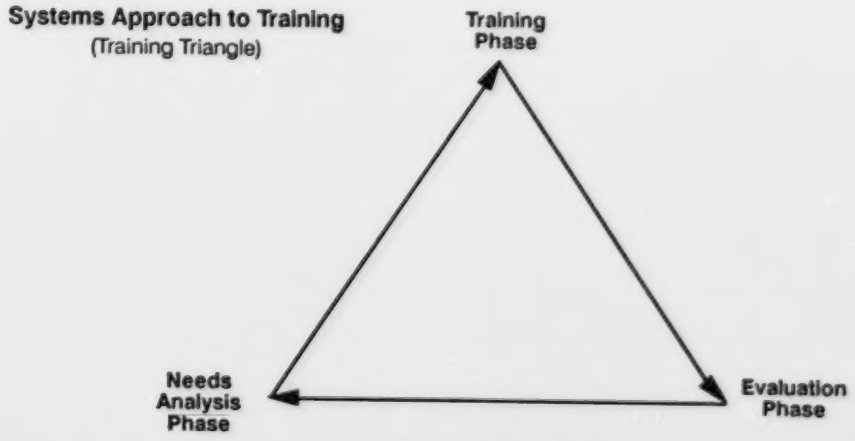

Figure 1: Training Triangle

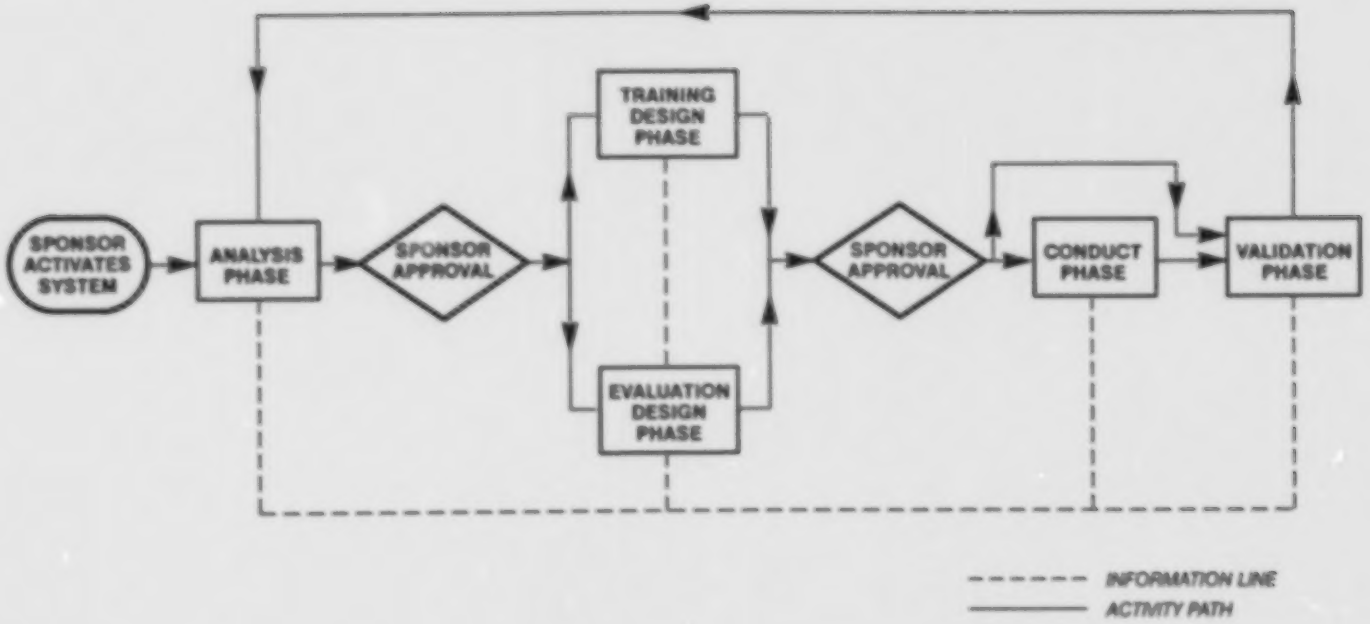

Figure 2: Systems Approach to Training Flow Chart

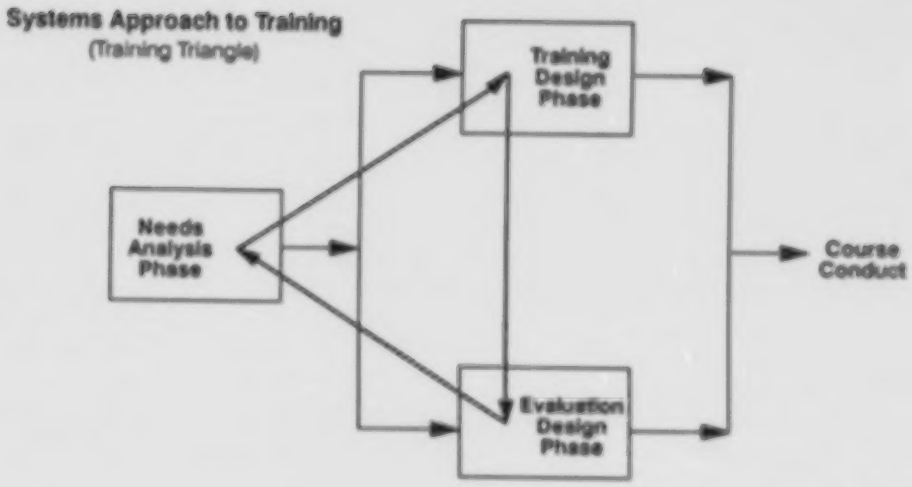

Figure 3: Training Triangle in Curriculum Design

Performance Evaluation

Figure 2 is the flow chart used to illustrate the various phases of curriculum design followed when developing training courses under the "Systems Approach to Training"[2]. Figure 3 illustrates the "Training Triangle" superimposed on the "Front End" portion of the Systems Approach to Training flow chart. Starting with a training need, in this case, simulation training in the various tasks of the ship's officer, the training path flows to the training design phase. Training developed during this phase should match the training needs defined during the analysis phase. At this point in the design process, the measurement or evaluation instruments necessary to ensure mastery of the knowledge and skills required by the job (task) are created. The completion of the triangle takes place when the trainee returns to the job and his performance matches the job (task) need.

The Maritime Training Centre, in conjunction with CCG Ship Safety Branch, has recently developed an approach to evaluating the performance of candidates under simulation training. My colleague, Mr. J.L. Maillette, will be presenting a paper in session six, titled "First Phase of Performance Monitoring in Marine Simulation." This paper will describe the method used to evaluate the performance of nautical candidates on Simulated Electronic Navigation (SEN) courses.

4. Conclusion

The Standards of Training, Certification and Watchkeeping Convention has given rise to mandatory nautical simulation training for Continued Proficiency Endorsements in both the deck and engineering departments. To meet this obligation, the Canadian marine training community will have to ensure to procurement and strategic location of modern marine simulators. These simulators must be capable of adapting to new technologies as they arise. Additionally, as nautical trainers, we will have to be constantly revising both the training objectives for the simulation exercises and the performance monitoring instruments we use to evaluate candidates.

[2] Systems Approach to Training, *Public Service Commission, Ottawa, Revised Edition, April, 1984.*

Appendix I

Purposes of the International Maritime Organization

The purposes of IMO as set forth in the Convention are:

(a) To provide machinery for co-operation between Governments in the field of governmental regulation and practices relating to technical matters of all kinds affecting shipping engaged in international trade; to encourage and facilitate the general adoption of the highest practicable standards in matters concerning the maritime safety, efficiency of navigation and prevention and control of marine pollution from ships; and to deal with the administrative and legal matters related to the purposes set out in this Article;

(b) To encourage the removal of discriminatory action and unnecessary restrictions by Governments affecting shipping engaged in international trade so as to promote the availability of shipping services to the commerce of the world without discrimination; assistance and encouragement given by a Government for the development of its national shipping and for the purposes of security does not in itself constitute discrimination, provided that such assistance and encouragement is not based on measures designed to restrict the freedom of shipping of all flags to take part in international trade;

(c) To provide for the consideration of the Organization of matters concerning unfair restrictive practices by shipping concerns in accordance with Part II;

(d) To provide for the consideration of the Organization of any matters concerning shipping and the effect of shipping on the marine environment that may be referred to it by any organ or specialized agency of the United Nations;

(e) To provide for the exchange of information among Governments on matters under consideration by the Organization.

Appendix B

Extract from Draft CCG Ship Safety Branch Certification Regulations

PART IV

Continued Proficiency Endorsements of Masters and Mates Certificates

23.26(1) An applicant for the continued proficiency endorsement shall:

(a) hold a valid certificate of medical fitness issued under the Medical Examination of Seafarers Regulations

(b) hold a valid pass in the sight test, see chapter 7, and

(c) have completed the MED and SEN courses required for the certificate held by the Examination Regulations, see section 23.26(2); and

(d) (i) have completed one years sea service, as master or deck officer during the five year period immediately preceding the date of application; see section 23.26(3); or

(ii) have been employed in a marine related capacity for a period of at least (two) years during the five year period immediately preceding the date of application, see section 23.26(4); or

(iii) pass an examination, the syllabus of which is set out in section 23.26(5); or

(iv) complete approved training as set out in section 23.26(6); or

(v) have completed not less than 3 months supernumerary sea service as a deck officer immediately prior to application, see section 23.26(7) and Note to 23.26(8).

23.26(2) The MED and SEN courses which must have been completed for issue of the Continued Proficiency Endorsement are:

	CERTIFICATE	SEN (NOTE a)	MED
(i)	FWKM/WKM 2MW/2NHT/2MFG	I	II
(ii)	ON2/CN2 1MTW/1MHT/1MFG	I	III (Note b)
(iii)	MM/ON1/CN1/COE CHT2SS/CHT/C1W/CFG	II	III (Note b)
(iv)	CMW	NIL	I or II (Note c)
(v)	Limited Master Limited Mate Ferry Certificates	As required for original issue of cert	
(vi)	Fishing Master, C1.4 Watchkeeping Mate, Fishing	NIL	I
(vii)	Fishing Master, C1.3 Fishing Mate C. of Service	NIL	I

(viii)	Fishing Master, C1.2 Fishing Master Fishing Master, Restrict C. of Service, Fishing Master	I	II
(ix)	Fishing Master, C1.2	II	III (Note b)

Notes:

(a) The former Radar Observer & Radar Simulator Courses will be considered as equivalent to the SEN I & SEN II Courses, respectively.

(b) A MED III course normally requires earlier completion of the MED II course; for continued Proficiency Endorsements, a compressed one-week course prior to the MED III is accepted.

(c) MED I or MED II as determined by the Examiner.

(d) There is no time limit on the date on which these courses were taken.

23.26(3) In all cases, service claimed under section 23.26(1)(d)(i) must be acceptable under the Regulations and Chapter 3 of this publication for issue of certificate held. The rules set out in Chapter 3 will be applied to determine eligibility. The one exception to this Rule is that service claimed for a continued proficiency endorsement to an ON I certificate need only meet the acceptance criteria for a CN I certificate.

23.26(4) The following marine-related positions will be accepted as meeting the requirements of section 23.26(1)(d)(ii):

- Shore Captains, Marine Superintendents, Operations Managers or like capacity in the employ of a ship owner or ship agent,
- pilots licenced by a Pilotage Authority, pilot superintendents,
- marine surveyors engaged in the surveyor inspection of ships, ship's equipment or cargoes,
- harbour, dock or berthing masters or their deputies,
- watchkeepers or supervisors in port operations, traffic or SAR centres,
- hydrographic surveyors,
- instructors and training officers in nautical subjects at federal, provincial or provincially recognized training institutions or for a shipping company,
- examiners of candidates for certificates of competency or qualification,
- casualty investigators engaged in the investigation of marine casualties,
- persons engaged in marine emergency planning and operations.

23.23(5) The examination required by section 23.26(1)(d)(iii) will consist of:

(i) the examination in subject 06, Navigation Safety, required for the certificate held

(ii) a practical examination on navigational instruments to the standards in subject 02, Instruments, required for the certificate held

(iii) an oral examination comprising changes which have occurred in the preceding five years in

(a) buoyage system

(b) routing, traffic separation and VTS system/regulations

(c) watchkeeping practices and procedures

(d) SAR procedures

(e) regulations/codes respecting hazardous and dangerous cargoes

(f) meteorological information and services

(g) pollution legislation

(h) industrial/personnel safety regulations/codes

(iv) a practical examination in radio and visual communications.

23.25(6) The syllabus of the approved training required by section 23.26(1)(d)(iv) is:

1. **Safe Navigation and Anti-Collision**

Collision regulations and buoyage systems. Routing systems and traffic separation schemes. Passage planning. Bridge procedures. Exercise in practical navigation. Principles of keeping a safe navigational watch. Revision of chartwork exercises. Practical operation of navigational equipment. Demonstrate ability to determine positions and compass error from celestial* and terrestrial observations. Search and rescue procedures.

2. **The Carriage and Handling of Cargo**

Principles of keeping a safe watch in port. Exercises in the use of stability information on ships. Methods of stress determination. Modern ship types; design features related to cargo handling, seakeeping and safety. Load/discharge procedures. An appreciation of the statutory requirements and recommended Codes relating to the carriage of grain, dangerous goods, chemicals in bulk, liquefied gases and other bulk cargoes.

3. **Operation of Ships**

Meteorological information and services. Revision of communication by morse and flag signals. Safety and other certificates required to be carried by ships and preparation for their renewal. Merchant shipping legislation concerning the safety of the ship. Legislation for the prevention of pollution. Regulations concerned with watchkeeping, shipboard safety and emergency situations.

4. **Ship Personnel Matters**

Safety legislation and Safe Working Practices Regulations. Manning qualifications, scales and training schemes. Discipline and procedures. Shipboard management. First Aid/Medical care aboard ship.

Note:

The foregoing syllabus will also provide guidance on the areas to be studied for those following section 23.26(1)(d)(v).

23.26(7) The service claimed under section 23.26(1)(d)(v) shall:

(a) have been performed in a supernumerary capacity as 2OOW or in a similar capacity understudying the OOW,

(b) be verified by the master on a certificate of watchkeeping service, EXN 25, and

(c) generally comply with the rules set out in Chapter 3 for acceptance of service for the certificate held.

Part V

Continued Proficiency Endorsement of Engineer Officers Certificates

23.27(1) Every engineer officer holding a certificate of competency who is serving at sea or intends to return to sea after a period ashore shall, in order to continue to qualify for sea service in the rank appropriate to this certificate, be required, at regular intervals not exceeding five years, to satisfy the Board as to his:

(a) medical fitness, including hearing and eyesight; and

(b) proficiency in marine emergency duties; and

(c) professional competence

(i) by approved sea service as a engineer officer of at least one year during the preceding five years, or

(ii) by virtue of having performed functions relating to the duties appropriate to the grade of certificate held which are considered to be at least equivalent to the approved sea service required in subparagraph (i), or

(iii) by one of the following

(A) passing an approved test, or

(B) successfully completing an approved course, or

(C) having completed approved sea service as an engineer officer for a period of not less than three months in a supernumerary capacity, or in a lower rank than that for which he holds the certificate, immediately prior to taking up the rank to which he is entitled by virtue of his certificate.

23.27 (2) The course or courses referred to in clause (1)(c)(iii)(B) shall include, in particular, changes in the relevant international regulations and recommendations concerning safety of life at sea and the protection of the marine environment.

SESSION 5

Engineering Aspects of Simulators for Training & Assessment Applications

Chair: *Sesto Vespa*
Transport Canada
Montreal, Quebec

ATELIER 5

Aspects techniques des applications des simulateurs à l'apprentissage et à l'évaluation

Présidence : *Sesto Vespa*
Transports Canada
Montréal (Québec)

Advances in Simulation

Len Allen
CAE Electronics
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Abstract

The tremendous increase in computer processing power over the last few years has allowed critical simulator systems such as control loading, motion and audio to become completely digital. It has also facilitated great improvements in visual systems for flight simulators.

This paper reviews the current status of these systems. The computer architecture for the CAE control loading, motion and audio systems is described. Some of the latest developments in visual systems including the CAE Fiber Optic Helmet Mounted Display are described.

Résumé

L'augmentation exponentielle de la puissance de traitement des ordinateurs au cours des dernières années a permis la numérisation complète des principaux systèmes qui composent les simulateurs, soit les systèmes de variation de l'effort aux commandes, de mouvement et de sonorisation. Elle a également été à l'origine d'améliorations considérables aux systèmes de visualisation des simulateurs de vol.

Cet article passe en revue l'état actuel de ces systèmes. Il décrit notamment l'architecture informatique des systèmes de variation de l'effort aux commandes, de mouvement et de sonorisation mis au point par CAE. Certaines innovations récentes en matière de visuels sont décrites, y compris le visuel de casque à fibre optique de CAE.

Introduction

A lot of advances in flight simulation have occurred since the first LINK blue box flight trainer came out in 1929. The power of computers has grown rapidly in recent years and has contributed to the development of every part of the simulator.

In this paper I would like to describe some of the recent advances occurring in flight simulation at CAE and elsewhere. In particular I will discuss control loading, motion, audio and visual systems, partly because these are in my area of immediate interest and partly because these systems have benefited most from the sudden expansion of computer power.

Starting first with control loading systems, the purpose of which is to generate the correct force gradients that a pilot would feel on the controls of the real aircraft. These forces in the aircraft are made up of many items including friction, inertia, spring forces and possibly aerodynamic loads.

The force gradients in the simulator are produced by a hydraulic actuator attached to the pilot's controls with a high performance servo drive system. This servo system has to have a very high response in order to give a realistic feel and in the past such systems were generally implemented using analog circuitry at least for the forward system. The major disadvantage of the analog approach is that it requires the use and sparing of a large number of specially designed circuit cards for each system and each aircraft type. These boards tend to drift over time and need regular maintenance. In addition, it is difficult to modify analog boards as new data becomes available.

As the computing power of computers and microprocessors has increased over the past decade, more and more of the functions have been moved into the digital domain. Most recently, the development of the Digital Signal Processors (DSPs) has allowed control loading and other such systems in the simulator to be fully digital and run at very high iteration rates. It is even possible to do real time processing at audio bandwidths, all on a single printed circuit board. This provides an environment capable of eliminating virtually all analog processing in the simulator.

System Architecture

In order to take advantage of the power of the DSPs it is necessary to create an environment which can couple them effectively to the simulator. CAE has developed a common architecture to do this -- a host computer containing operator interface and low iteration rate software connected by a high speed data link to one or more DMCs. The DMC is a general purpose microprocessor card which acts as

a chassis controller for the high speed DSP and I/O processor cards. The I/O cards are then connected to indicators and controls in the flight compartment. The use of the industry standard ethernet as the data link allows this system to be connected to a wide variety of computers. (See Figure 1.)

Control Loading

The control loading system uses this architecture, with a DSP card using a TMS320-C30 microprocessor, to do all the control loading model calculations. The C30 is the latest in the family of Texas Instrument DSPs. It can perform approximately 16 million instructions per second (MIPS) and processes 32 bit floating point numbers in a single cycle. This is about seven times as fast as a Micro VAX 3200 which performs just over 2 MIPS. The C30 can be programmed in a high level language such as C or ADA and we expect FORTRAN in the near future.

The iteration rate on the C30 card is 3000 Hz, which means that the servo loop to the hydraulic actuators can be completely digital. The power of this system makes it possible to directly implement the entire system block diagram as supplied by the aircraft manufacturer at a high iteration rate on one card. This allows accurate simulation of both static forces and dynamic response at the pilots controls. A convenient user friendly utility allows rapid adjustment of any parameter.

If more channels are required it is a simple matter to add more C30 cards to the chassis.

Motion System

The same system is used to drive the motion jacks, and one C30 card can do all the modelling calculations for all 6 motion jacks including the washout equations, axis transformations and buffets. The buffets can now be generated in all six aircraft axes. With the older design, only heave buffet was possible, because the axis transformation equations could not be done fast enough for other axes.

Digital Audio

This system uses the same basic host/DMC/DSP architecture as the control loading and motion systems, but the DSP cards are tailored for this application.

The voice signals are digitized, in an Analog Serial Box (ASB), close to the microphone and transmitted along a high speed serial bus to the audio chassis. Here they are digitally mixed with other voice signals and transmitted back along the data bus to the ASB where they are converted to analog signals to drive the speakers and headphones.

It becomes easy to add voice message playback and alteration of the instructor's voice or of the stored messages. Interference noise and crosstalk is greatly reduced in the digital system providing a better quality audio. The use of common cards provides design flexibility for special requirements and improves maintainability.

Visual Systems

One of the areas which has experienced the most dramatic development has been the visual system.

Many different approaches to visual simulation have been tried. One of the early approaches was the model board visual consisting of a three-dimensional scale model of the area to be simulated with a scale factor between 500 and 2 000 to 1. A closed circuit TV camera with special optics was servo driven to "fly" over the model and relay the picture back to a CRT display in front of the pilot. With a good model and good projection system this approach gave an excellent picture with a lot of detail especially close to the ground where it was important for landing. A number of these were built by CAE, LINK, Rediffusion and others. Some are still in use today.

However the model board is large and expensive and the flying area is restricted.

The real breakthrough in visual simulation has come fairly recently with the development of very powerful, relatively inexpensive digital computers.

It is now possible to generate accurate and realistic three dimensional models of the world using digital techniques. These computer generated visuals present full daylight scenes with color and texture and with a quality approaching that of a movie film. Creating the three dimensional visual data base, which has been a very labour intensive activity, can now be done using aerial or satellite photographs and digital reading techniques.

The power of a CGI system is measured by the number of surfaces and light points that can be generated. For example, the Rediffusion SPX can generate 500 surfaces and 1000 light points, and the Evans and Sutherland claim their new ESIG 4000 can produce up to 10 000 surfaces or 18 000 light points per channel. This is a very large number but still small compared to the detail in a real world daylight scene.

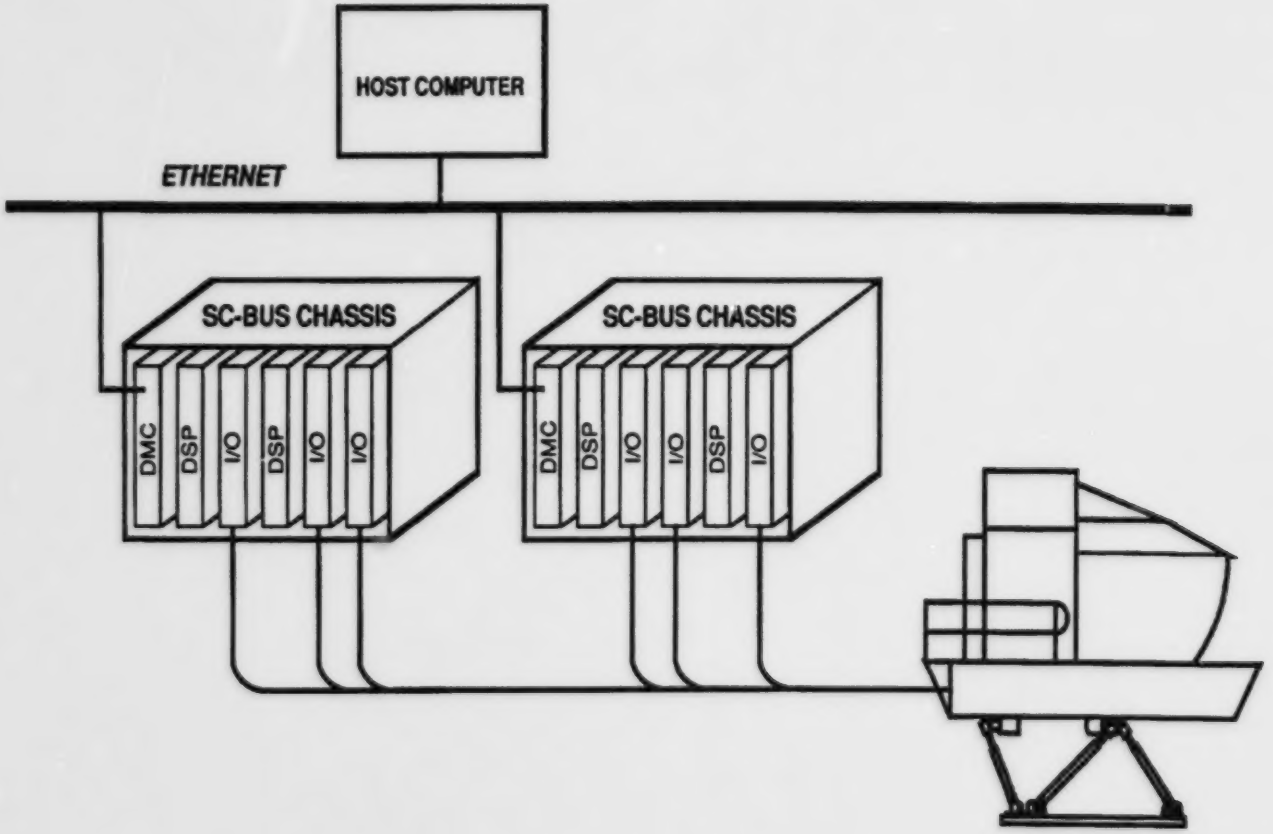

Figure 1: General System Configuration

Continuous improvements in computing power and modelling techniques allow better daylight scenes with realistic colour and shading. Actual airports are modelled so that the pilots can recognize and train in landing at all airports along the airline company routes.

A number of different companies produce visual systems at the present time. The major manufacturers of sophisticated visual systems are:

Evans & Sutherland	ESIG 3000/4000
General Electric	COMPU-SCENE IV and V and PT-2000

These are the high end systems for use on military simulators. They boast photo-realistic fidelity with full colour, texturing shading and up to 10,000 polygons per channel plus separate processing of features and terrain, level of detail modelling, Z buffering and much more. However, they are very expensive.

For commercial type simulators the following systems are available:

Rediffusion	SPX WIDE
Link Miles	IMAGE IV
Sogitec	GI 10,000
Hitachi	HIVIS 4
MDEC	VITAL VII with MULTIVIEW DISPLAY

Then there is a range of low cost visuals at prices around $1 million or less, using direct CRT displays. These are not suitable for full flight simulation but adequate for part task trainers. Manufacturers would include:

Silicon Graphics	IRIS 4D
Star Technologies	GRAPHICON 2000
Delta Graphics	FOCUS SR1
Paragon	
Ivex	VDS-1000

The above displays are usually limited to two dimensional terrain, no texture or terrain shading and generally a flat world.

For flight simulator use, various special effects can now be simulated such as clouds, thunderstorms, rain, snow, lightning, air and ground hazards such as other aircraft and ground traffic on the runways.

Modern simulation requires that all the special effects are synchronized in all the different simulator systems so that, for example, a storm cell will first appear on the cockpit weather radar and will affect the radio communication. As the aircraft gets closer it will appear in the visual scene and as he gets closer still it will be felt by buffeting in the motion system and by appropriate effects on the flight handling.

Field of View

One limitation to all the visual systems discussed so far is the field of view. The visual system display on most commercial flight simulators consists of a TV type CRT, viewed through a beam splitter and spherical mirror. Each channel provides a field of view of only about 30°, by 40°, although two channels can be butted together. Wide angle visuals are now becoming popular with very large continuous mirrors and with up to 5 projectors mounted on top of the cabin. These can provide a horizontal field of view of 150°, or even up to 200°. This is fine for commercial simulators where the main interest is in teaching the pilot how to approach and land at an airport. However, for military simulators where the requirement is to train pilots in air to air or air to ground combat, this field of view is definitely not enough.

One solution is the dome visual in which a large dome 30 to 40 feet in diameter is placed over the entire simulator to form the projection screen. The image is then projected onto the dome from projectors either inside or outside through holes in the dome. This gives a large field of view and is used for many military simulators. The disadvantages of this system are that a large number of projectors are required to cover the entire dome and ideally they should all be at the center of the dome. However this is also the point where the pilot's eye should be located.

As a compromise, domes are usually limited to high-resolution targets, or head slaved area of interest projected on to a low resolution background.

Another disadvantage of the dome is that it is large and therefore requires a large room size for the simulator. If a motion system is also required then there is the problem of mounting a large dome on a motion platform.

The Fibre Optic Helmet Mounted Display

A unique solution which has been under development for several years at CAE is the Fibre Optic Helmet Mounted Display. This is an area-of-interest approach where the display is attached directly to the pilot's helmet. The pilot views the image through a pancake window eye piece which places the image at infinity. The pilot's head position and eye position are monitored and used to control the computer generated image. The image is generated by light valve television projectors and transmitted to the helmet through high-resolution fibre optic cables.

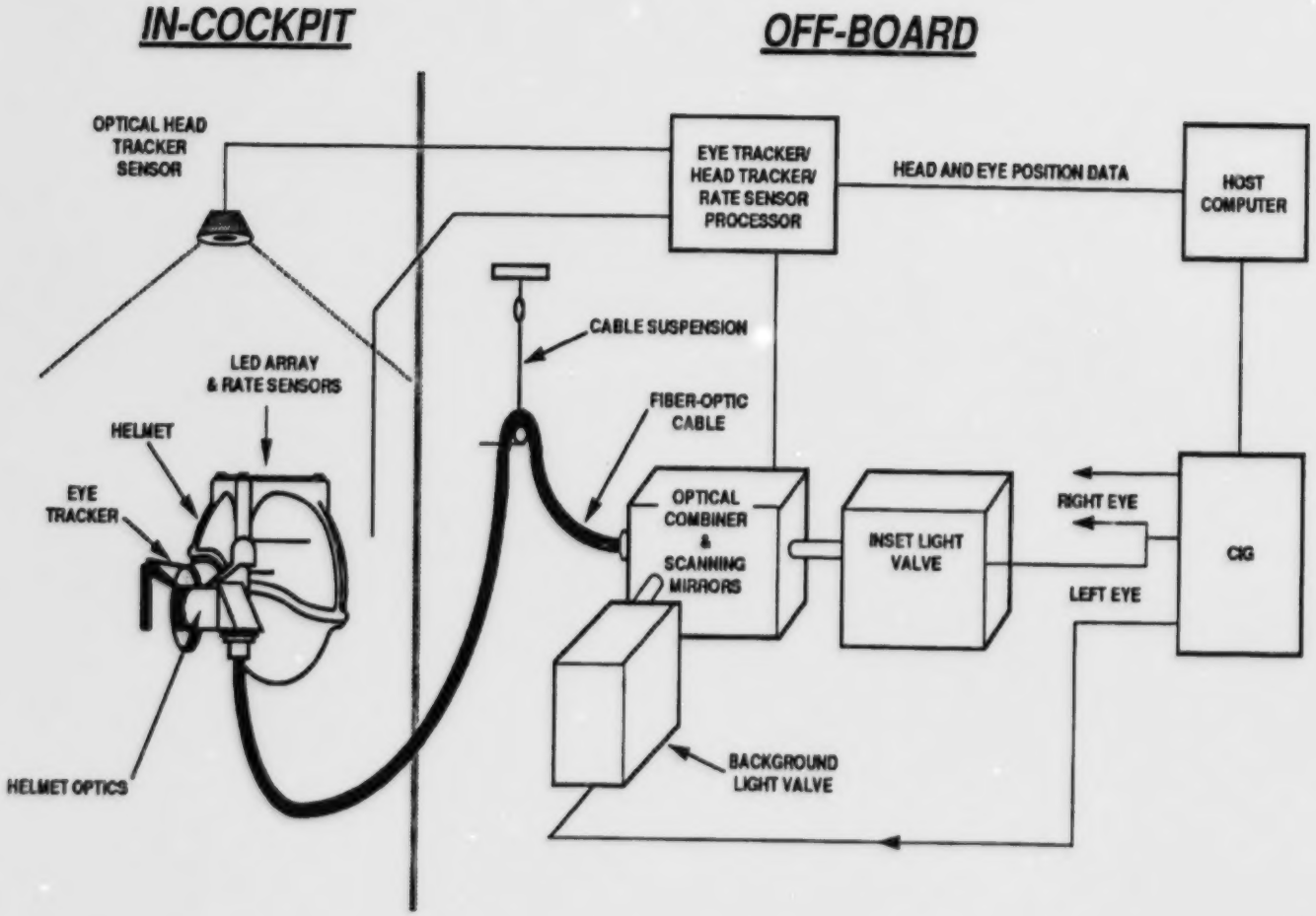

Figure 2: FOHMD System Components

The background instantaneous field of view is 127 degrees horizontally (82.5 degrees for each eye with 38 degrees overlap) by 66° vertically with a high resolution eye-slaved 18° by 22.5° inset. By tracking the eye and slaving the high resolution inset to it, surrounded by a low-resolution background to satisfy the demands of the eye's peripheral acuity, the system simulates a large high-resolution field of view. The display is collimated, full colour with very high brightness and contrast due to the use of the light valve projectors directly in the optical system. As individual display channels are used for each eye, with a 30° overlap, the system is capable of stereo display. As the pancake window is semi-transparent to light outside the optical path, cockpit instrumentation and controls can be viewed normally. In this way the most efficient use is made of the image processing hardware without restricting the pilot's field of view.

Figure 2 shows the main components that make up the FOHMD. The light valve projectors focus the image on the fibre optic cables that carry it to the helmet. The head tracker uses an array of LEDs in the helmet viewed by several TV cameras and the eye tracker monitors the reflection from tiny infra red light beams reflected off the eyeball. This information is sent to the host computer and image generator to determine the visual scene to be displayed.

The FOHMD is very compact and is ideally suited to air-to-air or air-to-ground combat training where the pilot looks in all directions for enemy aircraft or targets. If necessary it can be used for training in situations where space is at a premium such as on board an aircraft carrier. CAE is supplying several of these systems to Germany as part of an update to the Tornado simulators for use in low level training. The Germans will no longer use aircraft for low level training because of the number of accidents, and public pressure against low level training flights.

Microprocessor-Based Driving Simulator for Assessment of Brain-Damaged Individuals

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Abstract

In this paper engineering design approaches and concepts are presented relevant to a microprocessor-based automobile simulator under development by Concordia University for the Transportation Development Centre (TDC). The system's primary application is defined as the assessment of the readiness of brain-damaged and elderly individuals to take on-the-road driver training or to be re-licensed: designed modularly, it offers at relatively low cost a realistic driving environment including an interactive computer graphics visual system and a unique assessment module. After an overall description of the system, two challenging aspects of system design are treated, namely, the modelling of the vehicle dynamics and their translation into interactive computer graphics. Future engineering challenges are also discussed.

Résumé

Les auteurs traitent des concepts et des méthodes d'étude ayant présidé à la recherche sur un simulateur de conduite automobile à microprocesseur, menée par l'Université Concordia avec le concours financier du Centre de développement des transports. L'objectif de ce simulateur a été défini comme étant principalement celui de l'évaluation de l'aptitude des personnes âgées et de celles ayant subi des lésions cérébrales à reprendre le volant ou à entreprendre le volet routier d'un cours de conduite automobile. De conception modulaire, il permet de créer, à coût relativement faible, un environnement réaliste grâce à une visualisation infographique interactive et un module d'appréciation des performances unique en son genre. La description du simulateur est suivie d'une explication concernant deux aspects particulièrement difficiles de sa réalisation : la modélisation des lois de pilotage et leur conversion en imagerie infographique interactive. Les défis techniques qui subsistent sont également débattus.

Introduction

This paper focusses on engineering aspects relevant to a microprocessor-based automobile simulator being developed for the Transportation Development Centre (TDC) as a tool for assessing the readiness of brain-damaged individuals for either re-licensing or on-the-road driver training.

The rationale for undertaking the project lies, first, with the fact that many rehabilitation centres in Canada and other parts of the world have heavily attended driver assessment and retraining programs (Refs. 1,2,3). Typically, a brain-damaged patient referred to such a program is administered various perceptual and cognitive tests by an occupational therapist who then makes a decision regarding the patient's readiness to drive on the road, either alone or with a trainer. Simulators are sometimes used for these tests (Refs. 4,5,6), but low budgets permit only simple non-interactive types; more frequently, reliance is placed on makeshift devices. In neither case are measurement techniques sufficiently precise to afford the therapist a high level of judgment certainty. Thus, development of a low-cost interactive driving simulator with precise and suitable assessment capability responds to a clearly defined need by rehabilitation centres. Since therapists' decisions now necessarily lean heavily on the side of caution, the greater measurement precision of this tool was seen by TDC as opening up safe driving opportunities for a greater number of brain-damaged individuals.

The unique assessment module, incorporating magnetoencephalography/electroencephalography (MEG/EEG) techniques into an expert system, is described by Weinberg, Heron, and Svoboda in another part of the Proceedings. The report at hand purports rather to acquaint the reader with the overall concept of system design and to highlight two of its very challenging engineering aspects – the development and modelling of the vehicle dynamics and the translation of the model's output into suitable

computer graphics. The paper concludes with brief mention of project status and future engineering challenges with respect to the simulator.

System Description

The concept for and configuration of the simulator system resulted from a careful blending of specification requirements, available microprocessor and visual technology, advanced MEG/EEG techniques, and market cost constraints.

The overall concept of the driving simulator/assessment system is shown in Fig. 1 depicting the subject flow through the system. First (1), the patient/subject is diagnosed by a medical specialist who, on the basis of medical records and clinical tests, determines the patient's type of brain damage in terms of a special code. Next (2), the patient enters the simulator/assessment system and is subjected to a series of evoked potential (EP) measurements to confirm and refine the brain damage diagnosis. The set of measurements is chosen automatically according to the special brain-damage code. On the basis of the refined diagnosis, the system selects a suitable assessment procedure for the patient (3), results of which determine whether the patient is:

i. ready to return to driving or for on-the-road driver training (4)

ii. possibly retrainable for driving (5)

iii. not retrainable for driving (6)

The patients of class (ii) are then either fitted with suitable aids or subjected to cognitive retraining exercises designed to correct the deficiencies detected by the assessment system (7). After this process, the patients are re-assessed with the simulator and re-classified to either class (i) or (iii).

The system configuration is shown in Fig. 2. The modularly designed system consists of the simulator environment (1), the "main frame" microcomputer (2), the graphics work station (3), and the performance assessment module (5). The realistic simulator environment, based on a Mercury Tracer automobile cabin, is equipped with instrumented controls, video projectors with screens for visual cues, functioning driving instruments, and speakers with audio amplifiers driven by digital boards with sound storing/recall capability for acoustic cues. The steering wheel is equipped with an active force-feel system based on a DC-servo actuator. The brake pedal and accelerator forces are simulated by hydro-pneumatic and mechanical springs, respectively. The "main-frame" computer Epson 386 accommodates the simulator physical model, provides I/O functions, and serves as a facility for the operator/instructor (4) interaction with the simulator. The graphics station, consisting of the Iris 4D and Iris 3120 systems, generates the front visual and the peripheral/rear-view scenes respectively. It also, to a small extent, serves for some of the instructor/simulator interaction. The performance assessment module consists of the acquisition system for the collection of the electrophysiological and behavioural data for the patient/subject (6), associated circuitry for signal conditioning, and an Olivetti M280 microprocessor for the processing of these data and for the accommodation of the expert system.

Engineering Challenges: Interactive Vehicle Dynamics Model and Visual System

Two main engineering challenges were faced with respect to the simulator system: the development of the vehicle dynamics model software and of the visual system software. In both cases the development process required maximum utilization of the limited computing capabilities of the microprocessor hardware, while trading judiciously between system fidelity and an acceptable real-time performance.

Vehicle Dynamics Model

The vehicle dynamics model software, written in Fortran, determines the vehicle movements as well as the parameters of the car drive train in response to the driver's control inputs. The outputs of the vehicle model, in turn, determine the various environmental cues (visual, acoustic, force-feel, instrument readings, etc.) presented to the driver. The model software configuration shown in Fig. 3 is organized in seven self-contained blocks: engine (1), transmission (2), wheel-tire system (3), steering system (4), longitudinal movement (5), lateral movement (6) and attitude (7). Each of the above blocks can be tested, modified, and calibrated as an independent unit.

The philosophy of the vehicle model development was based on the fact that only a simplified dynamic model could be run in real time. However, to obtain acceptable fidelity, a complete vehicle dynamics model had to be developed as a starting point and subsequently simplified iteratively until optimum balance between the model fidelity and its computational speed was achieved.

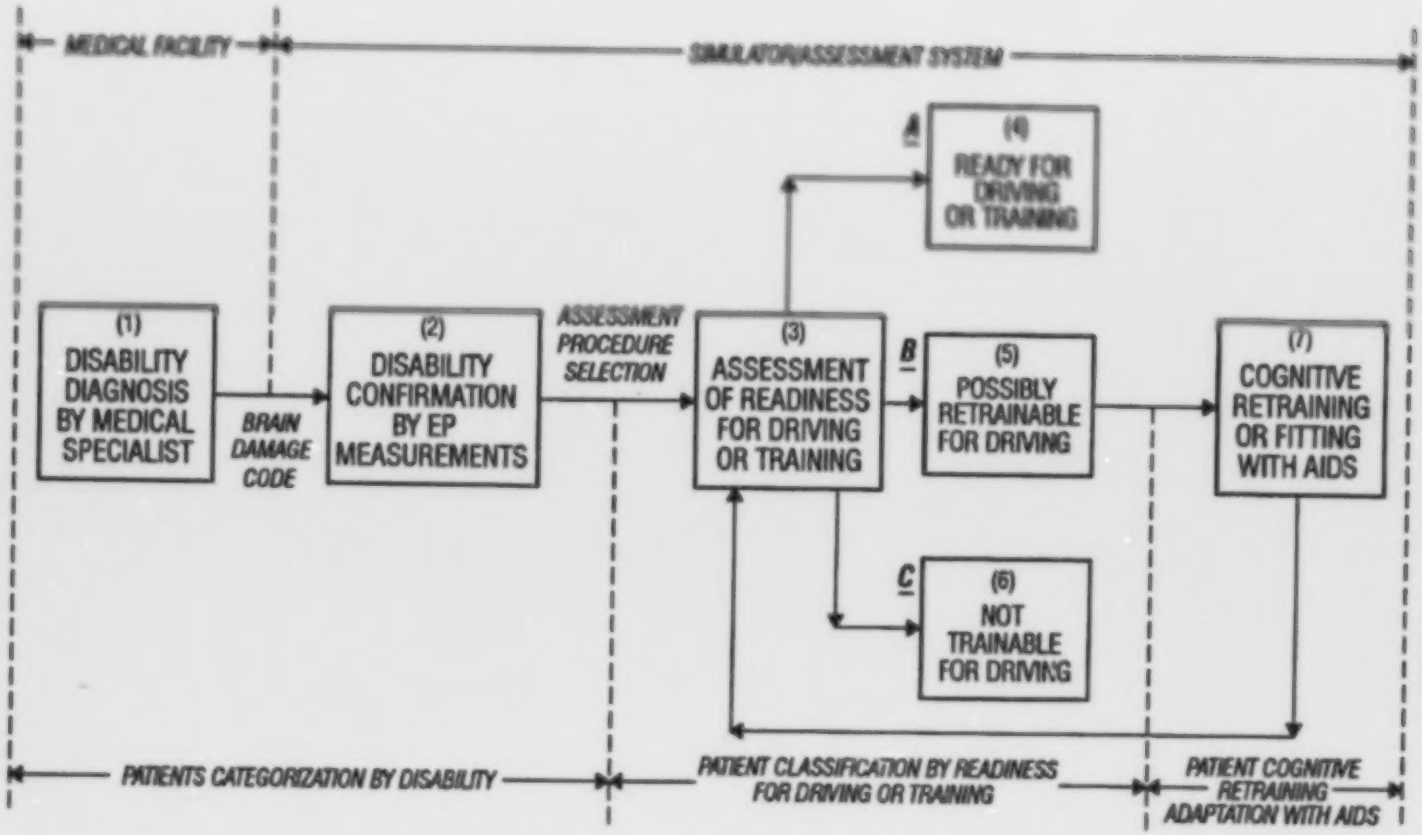

Figure 1: Patient Flow Through the Simulator/Assessment System

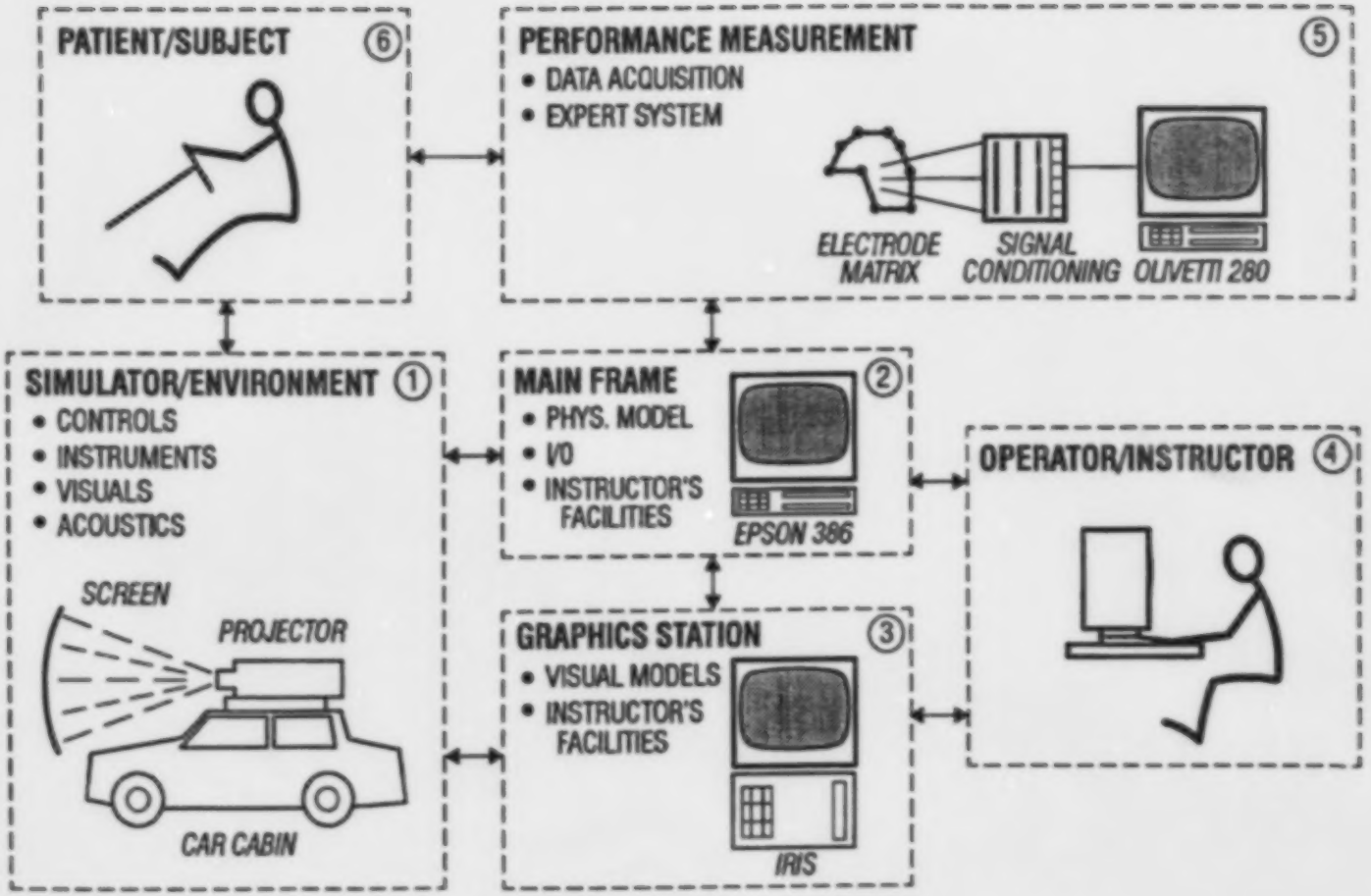

Figure 2: System Configuration

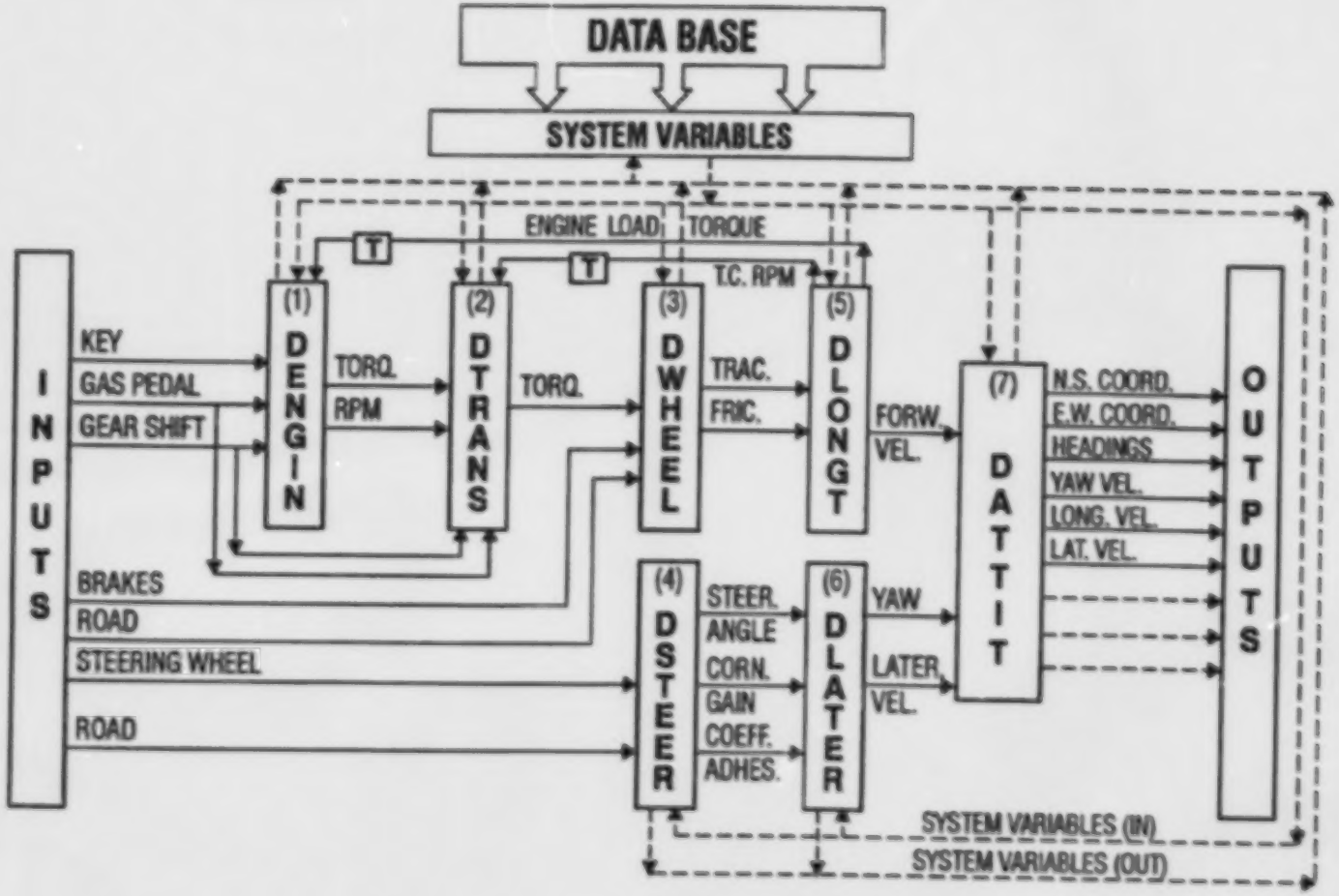

Figure 3: Vehicle Dynamics Model Structure

The active forces and movements of the drive train were calculated using the power-torque curves of the Mercury Tracer engine, combined with accepted thermodynamic algorithms used in the modelling of internal combustion engines (Ref. 7). Reactive forces and movements were computed using known road-tire friction factors and side force computational procedures (Ref. 8). Angular and linear accelerations and velocities were calculated according to Newton's second law of motion applied to the car mass, transmission, and wheels.

In the first attempt to achieve an acceptable computation iteration rate of some 10-15 Hz, the six-degrees of freedom multi-mass car system was decoupled into three subsystems:

i. the forward movement of the rigid car mass,

ii. the yawing and lateral movements of the rigid car mass,

iii. the pitching, rolling, and vertical movements of the three interacting mass systems, i.e. the car spring mass and each of the two axles.

In the second simplification round, calculations of the pitching, rolling, and vertical movements were omitted.

Visual System Software

The visual system software calculates the graphics algorithms used to display a three-dimensional scene consisting of static terrain, objects, and moving objects such as cars and pedestrians. The scene displayed is the driver's through-the- windshield view in real time (i.e. at an iteration rate of 10-15 Hz). A sample of typical visual scenes is shown in Fig. 4. As was the case with the vehicle model software, the graphics software algorithms were developed with maximum computing efficiency in mind.

The method of Binary Space Partitioning Trees (BSP Trees) was adopted as a basis for the simulator visual software (Ref. 9). The BSP method is useful for fast generation of static scenes viewed from different positions. However, for our purposes, it was modified to accommodate moving objects. The database was divided into 150 m x 150 m grid squares, each square representing a typical portion of city or highway scenes in a modular set fashion. Then a BSP Tree was built for each square at every iteration. The moving objects were then added to their respective squares. To simplify the task, it was assumed that each moving object is constrained to move within fixed boundaries (e.g. cars move only on roads). It was recognized that, in order to save computing time, only a small portion of a large static database representing terrain features and several moving objects would be viewed; accordingly, only those grid squares that would be in the driver's field of view were drawn.

The scene generation, carried out in real time, included three tasks. The first determined which grid squares were within view and sorted them out from farthest to nearest. Next, moving objects were added to the BSP Trees of the visible grids. Finally, each of these grids was drawn by traversing its BSP Trees.

Project Status and Future Engineering Challenges

Results of the first (proof-of-concept) phase of the project clearly show that microprocessor-based simulator devices are feasible for a broad category of applications. The goal of the second phase of the project, now in progress, is to develop the simulator further into a comprehensive driver assessment tool. At time of writing, it can be said that the feasibility of marrying the simulator technology and the MEG/EEG techniques appears to be well within reach. The work of the two relevant research teams has been greatly facilitated by design and fabrication of a low-cost portable version of the system. In preparation for demonstration tests, suitable driving scenarios have been developed, with modifications to the visual software and to the instructor's facilities being made accordingly. Results of these tests are encouraging.

Future challenges include the development of reliable assessment decision criteria and procedures, as well as their subsequent integration into the project using expert systems concepts. On balance, the system promises not only a unique solution to the problem of assessing brain-damaged individuals for driving, but also a basis of engineering and human factors simulator research and development that can be generalized to any type of vehicle/operator situation.

Acknowledgments

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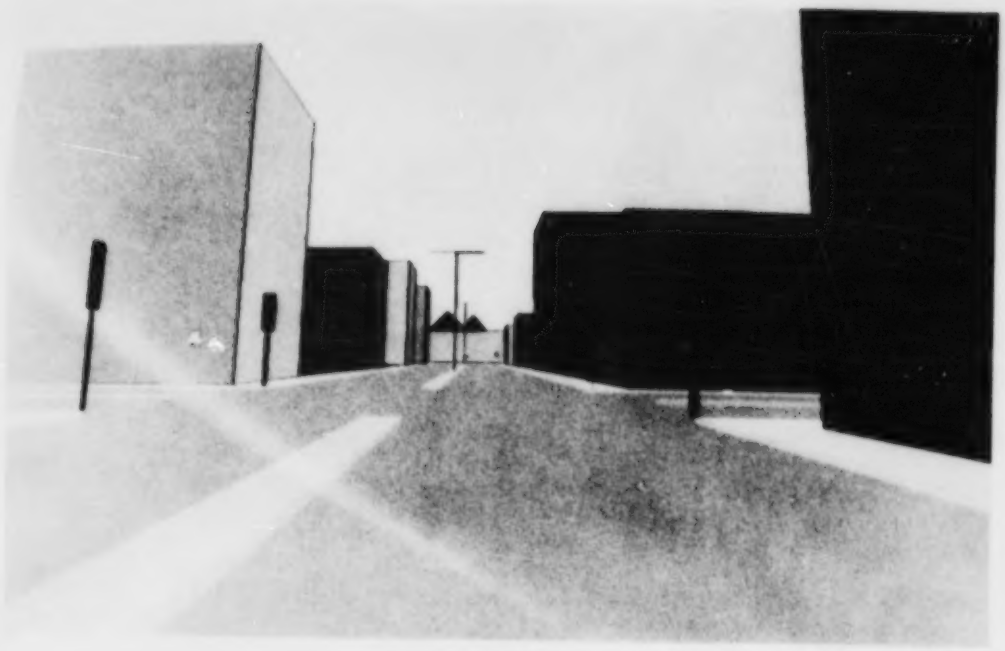
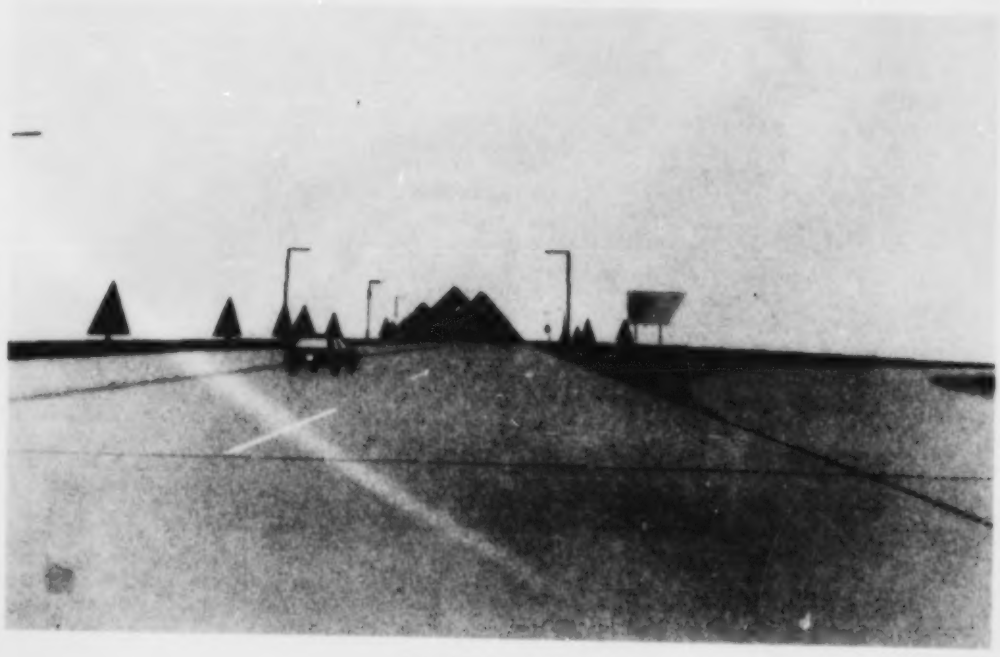


a) City Scene



b) Highway Scene

Figure 4: Typical Visual Scenes

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Recent Developments in Locomotive Simulators

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Abstract

This paper presents a number of recent advances in locomotive simulators. The functionality, systems and features of the full scope replica simulator used by Swedish State Railways are discussed, with emphasis on characteristics implemented for the first time. Differences in capabilities for the instructor are reviewed, focussing on the use of local and remote control positions and on report generation including performance evaluation. Recent advances in visual systems are described and finally the different types of simulator now available are summarized.

Résumé

Cet article fait état d'un certain nombre de progrès récents réalisés dans le domaine des simulateurs de locomotive. Il présente les fonctionnalités, les systèmes et les dispositifs du simulateur grandeur nature utilisé par les chemins de fer nationaux de Suède, en insistant sur les caractéristiques qui sont mises en oeuvre pour la première fois. Il passe en revue les améliorations apportées au poste d'instructeur, et met l'accent sur le choix qu'il offre entre la commande locale et à distance et la possibilité de produire des rapports, y compris des évaluations du rendement. Finalement, l'article présente les progrès récents réalisés dans le domaine des systèmes de visualisation et énumère les différents types de simulateurs actuellement offerts sur le marché.

1. Introduction

Locomotive simulators have been used to train engineers for many years now. Canadian National Railways and Southern Pacific Transportation Company have both been using simulators since the early 1970s. Both have upgraded their simulators in recent years, which is a testament to the effectiveness of simulator training.

Interest in locomotive simulators has increased dramatically in the last few years. Many railroads need the benefits which a simulator can bestow: reduced training time, improved safety, reduced energy consumption, efficient and effective refresher training. The push for more formality in licensing new engineers and in recertification adds further impetus.

As a result of this increased interest, new problems have surfaced and new solutions have been developed. This paper discusses a number of recent advances to indicate the current state-of-the-art.

2. Simulator for Swedish State Railways

DSL completed the installation of a full-scope replica simulator for Swedish State Railways (SJ) early in 1988. This simulator illustrates the state-of-the-art in all of its subsystems. It also incorporates a number of new techniques. The following sections describe the functionality of the simulator, the systems which make up the simulator, and certain noteworthy features.

2.1 Functionality

The simulation is of an ASEA Rc5 locomotive used in both passenger and freight service. The Rc5 is an electric locomotive which uses thyristor control and is rated at 4900 h.p. Swedish trains have European style buffers and couplers and UIC standard air brakes. Trains are short compared with those in North America. Simulator training is commonly provided for six and seventeen car passenger trains and sixty car freight trains. An operating feature which affects training requirements is that trains are operated by a single person crew.

One of the main reasons why SJ purchased the simulator is that many of their locomotive drivers are due for retirement over the next ten years. This will create a much greater demand for training at a time when pressure is increasing for maintenance of a good safety and performance record. The simulator is now operational in SJ's training centre at Mjolby, about 100 miles south-west of Stockholm. The training centre, which is located in a converted roundhouse, also houses an air brakes training facility with a brake rack and a facility for demonstrating and troubleshooting locomotive systems.

2.2 Systems

The various systems that comprise the SJ simulator are typical of those which make up a full-scope simulator.

2.2.1 Cab

The interior of the cab is a true replica of the interior of an Rc5 locomotive. All of the instruments and fittings, even the interior panels, were supplied by ASEA and are identical to those in a real locomotive. In addition to the normal controls (throttle, brake, etc.), it was a requirement to include the Automatic Train Control (ATC) system and a Fault Indication System (FIS). The FIS is discussed in more detail in Section 2.3.3. The ATC is a sophisticated braking control system which enforces speed limits if the driver does not take appropriate action.

2.2.2 Motion

The hydraulically-controlled motion system was specially designed to simulate the motions experienced in a locomotive. These sensations include general ride characteristics (e.g., roll and pitch) and longitudinal acceleration (e.g., slack run-in). In the case of SJ's high-powered electric locomotive, when used in passenger service, the effects of sustained acceleration and deceleration are also significant. This is simulated by pitching the cab either forward or backward as appropriate. This has an impact on the design of the visual system, which is discussed in Section 4.1.1. Another important sensation is the lateral force resulting from passage through crossovers at high speed. This is simulated through a lateral actuator.

This hydraulic motion system has the potential to deliver considerable force. Therefore, a fail safe control system is essential. Many safety interlocks are incorporated to ensure that neither equipment failure nor operator error can result in an unsafe condition.

2.2.3 Instructor Station

SJ elected to locate the instructor in a room next to the simulator. This remote console requires extensive displays to enable the instructor to monitor the student. The implications of such an operation are discussed in more detail in Section 3.1.2.

2.2.4 Sound

Sound simulation is based on recordings made on a real locomotive. Sounds include those created on the locomotive (e.g., traction motors, air brakes, compressors), and external sounds (e.g., track clatter, crossing bells). Sounds also include some important cues (e.g., pantograph going up, main circuit breaker closing). Recorded sounds were digitized and then replayed through a solid-state system in such a way that they respond correctly to the actions of the driver and the conditions of the simulated locomotive.

2.2.5 Visual

The visual system uses sequences stored on videodisc, created from video recordings of actual track. The video is replayed from two videodisc players with control giving the capability for alternate events. Alternative events permit the instructor to change the signal aspects encountered, change to an alternative track (e.g., take a siding) or select a scene in which, for example, an obstacle is encountered on the track. A number of special features were required because of particular characteristics of the Swedish operations; these are discussed in Section 4.

2.2.6 Computer

A locomotive simulator normally uses a general purpose mini-computer to run the software. The SJ simulator uses a DIGITAL MicroVAX II computer. DSL also supplies simulators with Hewlett Packard computers. Selection of the computer considers reliability and after-sales support equally with computer performance.

2.3 Features

2.3.1 Instructor

The instructor's role is to control and monitor the simulation exercise. The features necessary for this are provided at the instructor's console.

The instructor controls the exercise through a series of menus presented on the instructor's terminal. Through this terminal, the instructor can:

- Select an exercise;
- Change initial characteristics of the exercise, such as starting location and initial speed;
- Freeze the simulation and then continue;
- Select special events, such as low adhesion or failure of a particular component;
- Select alternative events, such as a different signal aspect or a different track;
- Initialize controls, to bypass operations which are not important in the current training exercise.

Because of the remote location of the instructor, various repeat displays are needed so that the instructor knows exactly what the student is doing. The Trip Log display shows an entry every time the student operates a control. This record may also be printed at the end of the exercise as an aid to debriefing.

An intercom enables the instructor and student to converse. Another audio communication channel provides a simulation of the student's radio; the instructor acts as the other party (e.g., dispatcher) in this communication.

2.3.2 Student

Inside the cab, the student has a full set of functional controls and displays. The feel and operation of the controls and the response of the displays match those of the real locomotive. This is achieved through precision in the simulation software and through the use of authentic instruments.

The student's intercom is through a microphone and speaker which are concealed behind the cab panels. The microphone is voice-activated for automatic operation.

The only in-cab display not found in a real locomotive is the Track Profile Display. This shows the student the track plan, grade, and curvature and is generally used when the student is unfamiliar with the territory. The instructor is able to switch this display off.

Within the cab, in addition to the instrument responses, the student experiences the same sound, motion, and visual effects as in the real locomotive. Some of these effects are included for realism. Others provide important cues to which the student is expected to react.

2.3.3 Fault Simulation

Fault simulation is extensive on the SJ Simulator. This is important to SJ because of the nature of their operation. They operate with a single locomotive and a single person crew and frequently with very short headways. In the event of a failure which disables the locomotive, it is a priority to move the train out of the way. The driver has a fault finding manual and is expected to diagnose and clear or bypass a fault.

In order to provide training in fault diagnosis and remedy, DSL provided the Engineroom, which is a section of the locomotive immediately behind the cab. The Engineroom contains the electrical controls and circuit breakers, the controls for traction motor #1, and the Fault Indication System (FIS). Since procedure requires the driver to stop the train before entering the engineroom, it was not necessary to simulate motion sensations. Therefore, the Engineroom is located off the motion platform, immediately behind the simulator cab.

The FIS includes a display inside the cab on a panel above the windshield. When the instructor initiates a fault (through the special event feature) there is normally a general indication through the in-cab displays and a specific message on the FIS display. This message will direct the driver to a trouble-shooting procedure. Typically, this will involve examining indicators in the Engineroom and then taking corrective action. A number of simulated faults affect the operation of traction motor #1. In these cases, the action will be to isolate traction motor #1 and proceed on three of the four traction motors.

3. Instructor Station Capabilities

A number of recent advances relate to the capabilities of the instructor station. This is the man-machine interface which is under the control of the simulator builder. The instructor's role is to both teach and evaluate the student. Each of these has its own requirements; the ability to freeze the simulator is important when teaching; and ability to objectively record and assess the student's performance is important when evaluating.

The instructor station requires features which enable the instructor to control and monitor a simulator exercise. The method of operation must be easy to learn and easy to use so that the instructor can concentrate on observing the student's performance.

3.1 Control Position

The different requirements of teaching and evaluating affect the selection of a local or remote control position. When teaching, the instructor will want to interact closely with the student, explaining and demonstrating. When evaluating, the instructor will want to be non-intrusive, so that the student has the sensation of being in a live situation without any unrealistic distractions.

3.1.1 Local Instructor Station

Examples of a local instructor station can be found at Southern Pacific Transportation Company and at Canadian National Railways. In both cases, the instructor is located behind the student, in an area immediately behind the cab bulkhead. A window with one-way glass can be opened to permit direct

communication between instructor and student. When this window is closed, the student is no longer aware of the presence of the instructor.

The main advantages of this arrangement are the ease of communication and that the instructor can get a better "feel" for the student's performance. This is particularly beneficial when teaching.

3.1.2 Remote Instructor Station

An example of a remote instructor station is at Swedish State Railways (SJ). The instructor actually sits in a separate room. An obvious result is that the instructor needs more repeat displays in order to know what the student is doing and why. The SJ instructor console includes the following displays:

- Trip Log, which records all student actions;
- Closed circuit television, through which the instructor can select views of the student's face or of the hands upon the controls;
- Repeat of the forward visual;
- Repeat of the track profile display;
- Repeats of the main instruments showing ATC, FIS, speed, brake pipe pressure, line current, and line voltage.

The instructor also has an intercom for communication with the student.

The advantages of this arrangement are that the extra space permits a good layout of displays and gives the instructor room to move. The instructor is not located on the motion platform; this is more comfortable for the instructor and simplifies the location of the videodisc players. There is no intrusion into the cab environment, which is beneficial when evaluating a student.

3.1.3 Combination of Local and Remote

The obvious conclusion of studying the advantages of local and remote instructor stations is to have both and get all the benefits. This is the approach which Metro North Commuter Railroad of New York City has adopted. When teaching, the instructor can sit behind the student and control the simulation exercise through a terminal. In evaluation mode, the instructor can operate the simulator from the remote console, leaving the student alone in the cab.

In going for the best of both worlds, there are some issues to be dealt with. There is some increase in cost through having a second terminal and a second seating position for the instructor. This is not very significant. A technical issue is to know which terminal is "in control" of the simulator. At Metro North, the instructor will switch control to the required terminal. A third issue is where to locate the videodisc players. At Metro North, the decision was to locate the players at the remote console. This does mean that the instructor will have to leave the local instructor station, if prompted, to change a videodisc. This is not a concern at Metro North since four disc players are provided and all exercises may be completed without disc changes.

3.1.4 Control of Several Simulators

Having both local and remote stations allows the instructor to use the one that best suits the training session. Another advantage is that one instructor can control several simulators through remote consoles provided that they are located together. This is Metro North's plan, where one instructor will be able to supervise all three simulators on the evening shift.

This type of operation can be appropriate where students perform practice exercises with minimal supervision. It can also be efficient for the type of evaluation sessions required for recertification.

Issues which must be considered include the need for videodisc changes and the need for spoken responses to a student; in response to a simulated radio message, for example. If the instructor is actually evaluating several students at once, the simulator must include comprehensive record keeping and report generation facilities.

3.2 Reports

The purposes of hardcopy reports produced at the end of an exercise are:

- To aid in debriefing the student;
- To provide a permanent record of the student's performance.

There are various levels of reporting available.

3.2.1 End-Of-Run Report

End-of-run reports have been used for many years by both Southern Pacific and Canadian National Railways. The end-of-run report is a summary of the exercise showing:

- Operational parameters; e.g., brake pipe pressure and leakage;
- Output parameters; e.g., break-in-two force;
- Train make-up; e.g., number of locomotives, number of loads, number of empties;
- Run summary, including total distance travelled, average speed, fuel consumption, gross ton miles per gallon, peak buff and draft forces;

- Duty cycle, showing time and distance in the various throttle, dynamic brake, and air brake positions;
- Operational report giving speed statistics;
- Energy and fuel consumption reports; and
- Details of ten highest buff and draft forces.

In addition, the end-of-run report can include full details of the train make-up and the trip log listing of all student actions.

3.2.2 Performance Comparison

The SJ simulator also includes a performance comparison feature. The objective is to compare the student's performance with an ideal run. For the comparison to be valid the two runs must feature the same train on the same track under the same conditions.

Two types of comparison are provided. The sequence-of-events comparison looks at certain actions of the student which must occur within a specified time window. The distance-based comparison examines certain parameters (e.g., speed, traction motor current, energy consumption) at regular distance intervals.

The instructor can request the current status of both comparisons at any time during an exercise. At the end of the exercise, comparison reports are printed. In addition to the conventional list of data, graphic plots of the distance-based comparison may also be generated. Results can be archived as either paper hardcopy or on magnetic media (diskette).

3.2.3 Performance Evaluation

Metro North have specified a performance evaluation feature to support their assessment of students. This will be particularly important when one instructor is supervising several students at the same time.

The Metro North scheme is essentially an expansion on the performance comparison described in Section 3.2.2. It comprises three parts:

- Exercise comparison, where various parameters (e.g., energy consumption, time in comparison with schedule) are compared on a distance basis;
- Event comparison, where student's actions (e.g., horn operation) are verified within a specified time window;
- Limits and penalties, where certain parameters (e.g., acceleration, in-train forces, speed limits, cumulative braking energy used) are compared with specified limits;

The data files for comparison can be created from actual runs, and subsequently edited if desired. Scoring is also data-driven so that the user can easily adjust weighting values.

If typical performance assessment criteria are examined they will include some factors which can be detected and measured by the simulator computer and some which can only be assessed by the instructor. Examples of simulator-detectable factors include compliance with speed limits, correct use of throttle and brakes, and correct use of horn. Examples of factors which can only be assessed by the instructor include observation of gauges, use of radio, calling of signals, and attentiveness.

Scoring methods can include:

- Overall pass/fail for critical items; i.e., failure on this type of item results in automatic failure of the entire test;
- Calculation of a score by adding marks for tasks performed successfully;
- Calculations of a score by deducting marks from a baseline score whenever an error occurs.

When evaluation is performed on or by a computer, it is also straightforward to weight individual tasks to reflect their relative importance.

4. Advances in Visual Systems

The visual system recreates the forward view as seen ahead of the locomotive. It is important in simulator training because it adds realism and provides cues. Realism helps to convince the student that the training is truly representative of actual performance. Cues are important in that they prompt some action by the student. An obvious example of a cue is a restricting signal, the sight of which should prompt the student to slow down.

4.1 Virtual Image System

A virtual image system is one which creates the impression of distance. With a projection system with a large screen, the impression of distance is created naturally because the screen is at some distance from the student. If the image is generated on a TV monitor, the effect of distance must be created optically, typically by creating a virtual image by placing a system of lenses between the student and the monitor.

A virtual image is important for realism. It also has benefits in reducing eye fatigue if a student is going to spend long periods of time on the simulator.

4.1.1 Attachment to Cab

In the case of the SJ simulator it was important to simulate sustained acceleration and deceleration. This was done by pitching the cab backwards and forwards. If this technique were to be used with a conventional projector and screen, every time the cab pitched, the horizon would move unrealistically. At best this would be distracting. At worst it would induce motion sickness.

The solution to this problem was to attach the visual system to the cab so that they move together. This is in fact the approach used on most flight simulators. This problem and solution are applicable to simulations of trains which can experience high levels of sustained acceleration and deceleration. This is not appropriate for typical North American freight trains where the longitudinal motion resulting from slack action is far more important then sustained longitudinal acceleration/deceleration cues. It is appropriate for high powered electric locomotives, particularly in passenger service. An additional benefit of this approach is that the simulator room does not need to be completely darkened, as is the case with a film projector and screen system.

4.1.2 Enhanced Resolution

When the visual image is made larger, either by projection or by a virtual image system, there is a loss in apparent resolution. With an image generated from video, the observer begins to see the lines and the gaps between them. This begins to detract from the student's sense of realism, although it does not greatly affect the visibility of cues.

The solution to this problem on the SJ simulator was essentially to use a high frequency system which writes the picture at twice the normal rate. The effect of this is to improve the apparent resolution (clarity or crispness) of the image. This same technique can be applied to video projection systems by using a higher frequency (and higher cost) projector.

4.2 Image Enhancement

Even with enhanced resolution it is not possible to distinguish the signal aspect (that is, the colours and/or arrangement of the lamps which give the signal its meaning) on the simulator at the same distance as in real life. This is a result of the remarkable ability of the human eye and of inherent limitations common to both film and video technology.

The traditional approach to this problem, as used at CN Rail to augment their 35 mm film projection system, is to use in-cab signals. With video systems it has become possible to superimpose graphics over the video image. This led to the type of enhancement implemented by Southern Pacific whereby a coloured dot is superimposed on the image of the signal. This dot is applied permanently during the video editing process.

The problem with Swedish State Railways was more complex:

- Ten different shapes of signal had to be accommodated – this meant that in-cab signals were not practical;
- Some signals had two lights on at the same time, sometimes with one flashing – this meant that superimposition over the signal image was not possible since the two lights were too close together;
- SJ's high speed operation requires signal visibility at a distance of 1 km (0.6 mile).

The solution was to superimpose a graphic representation of the complete signal, not on top of the signal, but in a fixed position on the left of the image. The advantages of this approach are:

- It can accommodate different shapes of signals with multiple lights;
- It avoids the problem of tracking the moving signal, thus cutting video editing costs.

The graphic representation appears at the point when the engineer would see the signal aspect in real life and it disappears when the signal is passed.

4.3 Special Features

The visual requirements for North American freight trains are generally straightforward. Signals are not complex, although semaphores may be encountered. Signalling tends to get more complex when dealing with passenger trains in areas of high density traffic. A number of issues have arisen in such applications which have required special features.

4.3.1 Flashing Signals

The problem with a flashing signal comes when the simulated train stops. The visual goes to a still frame, in which mode the signal will no longer flash. The signal appearing to go steady or to be extinguished can denote a change in the signal

aspect which may prompt the student to take a certain action which is not, in fact, appropriate.

DSL resolved this problem by switching between images on two videodiscs to create the flashing signal when stopped. While this may seem straightforward, it is complicated by the fact that the simulator cannot know in advance exactly where the student will stop. DSL developed a special algorithm to deal with this situation.

4.3.2 Alternate Moves

Another problem which can arise when the train has stopped at a signal is the presentation of a signal change which tells the student to proceed. The nature of the problem is very similar to that of flashing signals. Again, the solution is to switch between two videodiscs, taking into account the precise location at which the student stopped.

4.3.3 Alternate Scenarios

Another issue is that one alternate event often implies other; for example, a stop or restricted signal may require an appropriate approach signal. While this situation affects all simulators, it is likely to result in more complex scenarios in passenger operation in areas with high density traffic. In response to this, DSL enhanced the Alternate Event feature for SJ to Alternate Scenarios whereby the instructor sets up a complete sequence with one command.

The benefit of this is that the instructor is not distracted from teaching by having to decide on a realistic sequence of Alternate Events. Appropriate sequences can be pre-planned, and unrealistic sequences can be avoided.

5. Compact Simulators

Recently, the range of locomotive simulators has been expanded with lower cost compact simulators. Typically, these do not include a cab and have little or no customizing. They offer an economical starting point for all Railroads. An example of a compact simulator is DSL's Modular Simulator.

A compact simulator should be easily expandable. It should be possible to start small and grow without throwing anything away. As an example, an initial installation may not include a visual system which could be added later when some of the benefits of simulator use have already been obtained and demonstrated. It should ultimately be possible to add a cab enclosure and a motion system to expand a compact simulator into a full-scope simulator.

Compact simulators are suitable for both fixed and mobile installations. With a fixed installation, e.g., at a central training centre, full support facilities can be brought together at one location. The students travel to the simulator. With a mobile installation, the reverse is the case, where the instructor and the simulator travel to the students. A mobile installation could be in a motor home, a trailer, or even a container.

6. Conclusion

The use of locomotive simulators has been established for many years by the pioneers -- Canadian National Railways and Southern Pacific. We have seen recent advances that have expanded the capabilities beyond the traditional simulators for heavy haul freight operations.

Swedish State Railways use their full-scope replica simulator to train for operation of electric locomotives in both passenger and freight service.

This application posed new problems which required advances in several areas, notably:

- Fault simulation;
- Instructor capabilities;
- Visual system features.

The simulators now being built for Metro North will be used to train for operation of commuter trains. They will bring further advances including:

- Use of both remote and local instructor stations;
- Computerized performance evaluation to support the instructor's assessment of students.

We have also seen the introduction of modestly priced compact simulators which bring this technology within the reach of all Railroads.

For potential users of locomotive simulators, the conclusion is:

- You will be able to find solutions to your special problems; and
- You can get a simulator appropriate to your needs;
- The ever increasing range of features available is making simulators of benefit to an ever increasing range of users.

Simulation in the Canadian Patrol Frigate Program

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Abstract

This paper discusses the major differences between R&D simulators and training simulators as perceived in military programs, including stimulation versus simulation issues and instructor capabilities. Simulators developed by PARAMAX for the Canadian Patrol Frigate (CPF) program are described, including the Integrated Machinery Control System Trainer and the Combat Systems Test and Support Facility. The objective, development and training utilization of these trainers are presented. Lessons learned from CPF are also described. Proposed simulators for two other related programs are discussed, the new CPF Combat System Trainers program and the New Shipborne Aircraft program.

Résumé

Ce document traite des divergences principales entre les simulateurs conçus pour la recherche et le développement et ceux conçus pour l'entraînement, perçu d'une perspective militaire, et comprend une analyse de la stimulation par rapport à la simulation, et le degré de contrôle accordé à l'entraîneur. Les simulateurs développés par PARAMAX dans le cadre du programme de la frégate canadienne de patrouille (FCP) sont décrits, comportant le simulateur du système de contrôle intégré de la machinerie et le centre d'essai et de soutien des systèmes de combat. Les buts, le développement et l'utilisation de ces simulateurs pour l'entraînement sont exposés. Les leçons apprises du programme FCP sont également présentées. Sont examinés aussi les simulateurs proposés pour deux autres programmes connexes, les nouveaux simulateurs d'entraînement pour les systèmes de combat FCP et le programme du nouvel aéronef embarqué.

Introduction

PARAMAX, a division of UNISYS Defense Systems, is a company which manages complex Department of National Defence (DND) programs. PARAMAX is the premier military systems integration house in Canada. Most military programs attach a high priority to human engineering considerations and training simulation, and considerable research into these fields has been funded by the U.S. military. This paper will endeavour to show the direction that training simulation has taken in PARAMAX's most recent experience, and in two upcoming programs.

Major differences usually exist between simulators built for engineering (or R&D) purposes, as opposed to those simulators destined to support training. R&D simulators have more vehicle hardware, such as avionics, which must be "stimulated", while trainers will have simulation of hardware (and its embedded software) wherever possible. This rule applies badly, however, to situations where the vehicle hardware/software is in a prototype state, and trained personnel are required from the first day of vehicle operation. In the latter case, the training devices should also incorporate actual vehicle hardware/software, with updates to occur concurrently or subsequent to vehicle certification. Fidelity is usually enhanced by using actual vehicle hardware and software, but there are corresponding cost considerations.

South of the border, however, military programs can involve procurement of so many units of the same training device that the provision of expensive hardware for each is not as cost-effective as equipment simulation, and waiting longer for trainers based on simulation of eventually "baselined" equipment has been advanced as the preferred approach.

Functional control of simulators differs depending on the application. The R&D experimenter prefers limited tests, with single stepping capability, and visibility into all variables. The instructor in a training environment needs a station that provides visibility into system-level variables, permits control and monitoring and incorporates human engineering aspects that will allow information to be assessed easily and fully throughout the duration of a long session.

Range of simulation is also a consideration, with R&D principally interested in extremes for certification, while trainers focus on nominal ranges of operation, and inclusion of realistic representations of "contaminants" such as the environment, which

are often merely approximated in the R&D application. Moreover, the experimenter frequently needs only a functional facsimile of the man-machine interface, while the trainer needs exact physical and tactile similarity in order to maximize positive training.

Canadian Patrol Frigate Program

In the Canadian Patrol Frigate (CPF) program, in which Saint John Shipbuilding Limited is the prime contractor, PARAMAX is providing the Integrated Machinery Control System (IMCS) and the Combat Systems (CS), and is tasked to provide operator/maintainer and team training, as well as associated training equipment for these two major shipboard systems. Integration of both the IMCS and the CS required simulation environments, and limited funds were available for trainers. The solution, whereby R&D and training co-existed on the same devices respectively, evolved on the IMCS, and occurred by design on the CS. The simulation program was fraught with all the maintenance problems and shifting configurations typical of R&D applications, but time conflicts were resolved and the training program was completed. How this was accomplished is outlined below, followed by descriptions of how PARAMAX will hopefully avoid a similar dilemma in the future.

IMCS Trainer

The CPF IMCS provides control and monitoring of the ship propulsion plant (Diesel and Gas Turbine), propulsion train, ancillary plants, electrical generation plants and interfaces with electrical distribution switchboards, the Damage Control System and auxiliary systems. The IMCS also provides health monitoring of all major items of the above-mentioned plants. Information is provided to operators through graphical display pages incorporating active schematics.

The IMCS Trainer, supplied to PARAMAX by CAE Electronics, is composed of the actual Man Machine Interface (MMI) consoles found in the Machinery Control Room, an embedded IMCS interfaced to simulated sensor inputs and an Instructor Station. Operator training on the Trainer is achieved by taking the trainee through operational scenarios, including failures, which are realistically represented on the IMCS MMIs. For maintenance training, the full diagnostic capability of the IMCS is available through the Maintainer/Electrical Console, and through the IMCS local diagnostic access.

In addition to normal operations, the basic trainer concept is to train operators and maintainers of the IMCS to react appropriately to dangerous and unusual conditions which cannot be safely or reasonably created in a live environment aboard ship. The consequences of incorrect operation in the event of system failures are also realistically portrayed. Trainees include the IMCS Harbour Watchkeeper, IMCS Sea Watchkeepers (Electrical and Mechanical) and the IMCS Maintainer. Examples of the many tasks trained on this device are the manipulation of display pages to extract information and effect control, recognition of alarms, reconfiguration of the mechanical/electrical systems, adjustment of sensor setpoints and execution of Built-In-Tests.

The Instructor Station is basically a standard computer terminal from which the instructor can initiate lesson plans, implement malfunctions, change simulated plant interface control and scan points, make snapshots of the system configuration and control replay of the training session for debrief purposes. To date approximately 60 scenarios have been developed to support the IMCS training program. Coupled to classroom instruction, the Trainer has been used successfully to train IMCS operators and maintainers for Ship #1, the HMCS Halifax.

IMCS Trainer Development

From the outset, the IMCS Trainer was conceived with traits more associated with the R&D simulators described above. The Government had reserved an IMCS shipset, thus deciding the simulation/stimulation issue, and therefore design of the Trainer was seen more as an engineering than a training exercise. As a result, the Trainer is limited to a one position/one trainee throughput, which could have been improved had the design been training-oriented. Moreover, the Trainer became highly attractive as a testbed for the development of the IMCS. When PARAMAX training personnel entered the fray at the design review stage, it also became clear that these subject matter experts had exactly the human engineering knowledge necessary to assist in the development of all the IMCS display pages. This definitively furthered the use of the Trainer as a testbed. Use of the Trainer led to the detection and correction of problems associated with console joysticks and screen glare.

Some shipset Factory Acceptance Tests were carried out using the Trainer, but it is not clear whether delivery of the Trainer was affected by this policy. After the Trainer was delivered, however,

the shipboard IMCS and Trainer software subsequently diverged. This is because training had to commence, as is usually the case in a prototype environment, before development of the shipboard system was fully complete. The training program would have been adversely and inhomogeneously affected by random updates occurring during Ship #1 crew training. Differences between the current ship IMCS software and the Trainer have been stressed in classroom training so as to minimize negative training. The result, paradoxically, is a fully trained crew now operating on the HMCS Halifax, without Crown final approval of the IMCS and by extension, the IMCS Trainer.

Combat System Test and Support Facility (CSTSF)

The CSTSF is a 16 000 square foot shielded area installed at PARAMAX in Montreal to achieve the integration of the CPF Combat System. The CPF Combat System is composed of the following equipment:

- Surveillance Radars and IFF System
- Fire Control and AAW Weapons System
- SSM, CIWS, and ASW Weapons System
- Electronic Warfare System
- Navigation System
- Underwater Combat and Control System
- Communications, MPS/CCMS and MET System

The primary goal of the CSTSF Physical Mockup/ Functional Mockup (PMU/FMU) is as follows:

- Provide a facility to certify the Combat System operational software, including Command and Control Software (CCS).
- Test and integrate Combat System hardware and software.
- Provide on-line readiness monitoring and equipment/function fault isolation testing.
- Provide a portion of the "objective evidence" required to complete the Combat System Acceptance Testing for Ship #1.
- Provide a facility for team training of the first six ships' crews.

CSTSF Operations Room

The Operations Room is the centre of the Combat System on board CPF. It contains the hardware, software, and personnel necessary to effectively integrate the sensors, weapons and communications aboard ship. The Operations Room provides its personnel team with information necessary to perform their assigned tasks in an effective manner, and the tools necessary to exercise control over the fighting resources available on the ship. The PMU duplicates Operations Room equipment aboard ship including location, wiring, cable routing, air conditioning, noise reduction, and lighting.

In the PMU, all essential Operations Room equipment is functional and all CPF Combat System commands, decisions or responses are initiated in this room. The command organization personnel interface with the remainder of the Combat System equipment via various Standard Displays and special Control Consoles. In addition, information and data can be exchanged with other simulated platforms using the communications console and the Link 11 control panel.

The Operations Room is crucial for final hardware/ software integration tests when realistic combat scenarios are enacted and the capability of the CCS is tested. In addition, the Operations Room is utilized for establishing human factors, safety and reliability guidelines and for team training exercises.

CSTSF Combat Systems Mockup

In adjacent rooms the Combat Systems FMU houses all remaining Combat System spaces and equipment with the exception of equipment which cannot be used in its normal mode of operation at a land based site (such as Harpoon Missile Launcher, CIWS gun). For such equipment, special hardware simulators have been designed to enable normal operation of the Combat System as on-board ship. Antenna assemblies are earmarked for mounting on towers close to their associated equipment just outside the CSTSF building. However, for the Electronic Warfare systems the antennas have been installed inside the shield.

Each hardware simulator is first utilized to check out its associated equipment within the Combat System subsystem in which it resides. For example, stimuli emanating from the Radar Simulator are applied to the Search Radars (SPS-49, Sea Giraffe) to check-out the complete radar subsystem. In the final phase of the hardware/software integration, a group of (or all) hardware simulators are operated to demonstrate the ability of the Combat System to respond effectively to combat situations.

CSTSF Simulation Control

The Simulation Control Centre (SCC) is used for initiation, control and monitoring of canned or programmed scenarios required to stimulate either the software operational control modules or the hardware simulators. The Simulation (SIM) computers are equipped with software modules capable of exercising and directly interfacing with the CS Serial Data Bus and Command and Control computers.

Three types of simulation functions are implemented at CSTSF as follows:

- Software Simulation, in which the command and control software modules are exercised by software simulation of the equipment hardware and software operations through the various interfaces using simulation software modules residing in the SIM computers. In case of CS equipment malfunction, software simulation can be self-sufficient for conducting a coordinated scenario.
- Equipment Simulation, in which a hardware simulator substitutes for a particular equipment (e.g., Bofors gun, Harpoon missile). The simulator provides normal responses to transmitted Combat System signals using internal hardware/software simulation.
- Software and Equipment Environmental Simulation, in which the environment of dynamically moving targets, clutter, jamming, multipath effects, target fluctuations, background noises, and propagation factors are simulated as inputs to the sensor equipment such as: (1) radars, (2) EW, (3) sonar and sonobuoy, (4) bathythermograph, and (5) depth sounder. This function also includes simulated outputs of own ship speed, heading, pitch, and roll to the navigation switchboard.

Training in the CSTSF

Both operator and maintenance training for Ship #1 crew has been provided in the CSTSF. Since actual shipboard equipment abounds in the CSTSF, maintenance training has been very successful, although access has been hampered by integration activities and equipment failures. In addition, throughput tends to be slow since a typical laboratory session will cycle four maintainers in sequence through one piece of equipment.

Operator training is initiated by a familiarization software package called C-Train. C-Train is loaded into a particular shipboard display handler computer, and allows the operator to exercise all the functions and quick action buttons associated with that display. Subsequently, operators are exposed to their simulated/stimulated subsystem linked with CCS, and finally all operators together undergo team training where all elements of the CPF and its crew are exercised in a lengthy scenario.

Future CPF Combat System Trainers

PARAMAX is currently responding, with the assistance of other Canadian companies, to a DND Request for Proposal for new CPF Training Equipment. These new trainers are meant to apply new technology to dramatically expand CP training beyond what the CSTSF has provided to date, and to free training from the limitations imposed by the integration environment. Two trainers are required for this program:

- an Operations Room Team Trainer (ORTT), with two Operations Rooms (an important new capability since crews typically operate in consort with other crews). The ORTT will provide much richer tactical and environmental conditions than the CSTSF, enhanced instructor control and an extensive debrief capability. However, the requirement to run the still changing operational CCS software unmodified, as well as C-Train software, means that the ORTT will still contain commercialized versions of actual ship computers, while the rest of the trainer will be equipment of commercial design only.
- a Maintenance Procedures Trainer (MPT), in which Computer Based Training (CBT) interactive graphics are used to replace much hands-on laboratory maintenance training, thereby increasing training throughput. The MPT requires extensive CBT courseware development in order to translate traditional classroom and laboratory instruction to the CBT environment. The CBT courseware will be provided in both official languages.

New Shipborne Aircraft Program

European Helicopters Inc. (Canada) is the prime contractor providing the EH101 helicopters which will replace Canada's aging Sea Kings. The EH101 will be based on the CPF, as well as other platforms. PARAMAX, in addition to providing integration of the EH101 avionics, is the principal training subcontractor.

Training for the NSA has been handled rigorously from the start, with detailed Definition Contract plans submitted for all aspects of training. In the area of training media, an early requirement was a Training Media Selection Criteria Report, which embodied an algorithm for determining the most effective mix of media, from overhead projectors to the helicopter itself, for achieving the training of all job related tasks in both air operations and air maintenance roles. This algorithm was applied by training Subject Matter Experts (SMEs) (ex-DND personnel) working in collaboration with engineers, enabling the SMEs to evaluate the potential benefit and throughput of a given medium, while at the same time establishing and sometimes pushing the current state-of-the-art for that particular medium. This activity led to a requirements study report rich in utilization figures, measures of effectiveness and baseline functional requirements for training devices. These last were embodied in subsequent training equipment specifications.

A development rig, including stimulators and simulation is also being designed to accommodate integration of the helicopter Mission Systems, but unlike the CPF program, this activity is being kept clearly distinct from training equipment.

Conclusion

Rapidly changing modern computer technology has rendered military vehicle hardware and software sufficiently unstable that effective training equipment solutions are difficult to devise. In Canada, where military training budgets are traditionally limited, and major procurements somewhat distant from one another, changing technology is fast enough to make lessons learned from one program possibly unusable in the next. However, as training becomes more important, and as superpower military tensions lessen, PARAMAX hopes to provide continuity in new programs through permanent combined systems and training expertise.

SESSION 6

Human Factors Aspects of Simulators for Training & Assessment Applications

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ATELIER 6

Aspects ergonomiques des applications des simulateurs à l'apprentissage et à l'évaluation

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Applications of Man-in-the-loop Simulation Technology to Training System Design

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Abstract

Two core issues are addressed in this paper:

1. The problem of developing valid effectiveness criteria for simulators as advanced training systems; and
2. The problem of translating simulator training effectiveness results to definition of cheaper, less complex and therefore more accessible training devices.

Résumé

L'auteur traite des deux thèmes suivants :

1. Élaboration de critères valables pour analyser l'efficacité réelle des simulateurs utilisés comme aides avancées à la formation.
2. Transposition des résultats de cette analyse à la définition d'aides à la formation plus accessibles, c'est-à-dire moins coûteux et moins complexes.

Historically, the primary target of simulator use in training assessment has been the design of simulators per se. A persistent problem inherent to this activity has been the determination of relevant criteria for assessing the effectiveness of training in the simulator and a variety of measures have been developed (e.g., transfer of training, fidelity of simulator characteristics to those of the simulated system/environment, student performance in the simulator) to varying degrees of success. Part of the difficulty has developed due to attempts to define requirements on a technology driven basis (what will this new feature do for me) rather than upon the results of a specific front end training requirements analysis (what do I need to train and to what level). The fidelity requirements of a training system to support decision task training (which is procedures intensive and requires provision of all relevant data for assessing problems such as weather conditions at destination, interaction with Air Traffic Control, etc.) may be very different from those for support of skilled sensory/motor task training (which is skill intensive and requires a closely representative sensory/perceptual environment in real time). Student population characteristics are another critical determinant. For example, in civil and military training tasks, student population and requirements are very different:

Civil: Pilots are experienced, with advanced sensory/motor skills already developed: Simulation training is used to tune existing skills to new equipment and/or procedures and for skill maintenance.

Military: Pilots are inexperienced or even ab initio: Simulator training is used to introduce new skills tasks.

As well, the types of training assessment criteria which are appropriate to apply to simulator effectiveness (as a training system) may differ in the context of the training requirements. In civil training an issue is that transfer of training methodology applies primarily to initial acquisition of flying skills – little methodology is available for assessing prevention of loss of skills or retarding degradation of skills due to lack of practice.

N.B. *While well-learned manual components of skilled flying tasks are resistant to loss over time, procedural components (e.g., in instrument flying tasks) can degrade to unacceptable levels within one month.*

In military training the issue is how valuable are simulators (and what features) in training skilled flying tasks? (Research goes back to the early 1950s, essentially from the time more than simple procedures training feasible.) What training effectiveness modes apply to what tasks? How much high (expensive) fidelity could be given up and still achieve acceptable training?

N.B. *While military simulators tend to be more complex and more expensive than civil simulators, they are utilized less (40-96 hr/wk vs 126-140 hr/wk).*

The second issue addressed in the present paper is that although simulators are much cheaper to purchase and operate than military and large

transport aircraft (the median is on the order of 12 %) they are still relatively expensive and complex machines. Much of the current thrust in simulator/ training system research is towards determining which aspects of training can be off-loaded from simulator to PTT (Part Task Training) or CMT/CBT training systems, in the way that aircraft hours have been off-loaded to simulators.

A challenge arises in that the dividing line between decision and skill related tasks can be difficult to define when one is training an integrated task (such as flying an aircraft in specified conditions) either in an aircraft or in a high fidelity flight simulator. The fidelity requirements of the less capable training system must be defined as with sophisticated simulators, and can be addressed in the same fashion, (i.e., appropriate front-end training requirements analysis). However, analysis alone cannot adequately define training system capability with respect to level of skills to be attained with specific sets of feature combinations. A systematic evaluation of training results, with training system characteristics strictly controlled, must be conducted to validate the analysis. This approach has been attempted from time to time in the past but no simulator has been designed to systematically vary fidelity features under experimenter control. Studies in simulators not purpose-built for this application have generally involved the disabling of one feature or another (e.g., in simulators with both outside world visual displays and motion platform, turn off one or the other). Since training simulators are designed and built as integrated systems, characteristics of such components as motion platforms are tuned to accommodate the visual display and vice versa. This means that the individual systems are not optimized for function in isolation and use of them in that condition may skew results.

Use of simulation to define appropriate characteristics for both sophisticated training devices and less complex systems could involve application of a highly sophisticated simulator, developed to the technical state of the art, but purpose-built to allow planned reduction of complexity in specific features, so as to allow a structured analysis of the training value of different levels of those features. Description of an example of such a device, a Simulator Complexity Testbed (SCTB) for the United States Army and the rationale for its development follows.

The U.S. army audit agency and general accounting office have criticized the lack of quantifiable data regarding flight simulator training effectiveness. In order to address this deficiency, a testbed to examine the minimum essential elements necessary for a simulator or training device to effectively train aviation individuals and collective tasks in a doctrinal context is being developed. It will address the role of simulators in a total training system, generate empirical data regarding simulator design requirements, and function as a testbed for man-in-the-loop testing of hardware, doctrine, and operational requirements.

Research objectives are:

- Empirical definition of training device requirements, desktop through full mission simulator, for maintenance of combat readiness of unit aviators.
- Quantification of factors affecting training transfer – fidelity relationships.
- Development of tactics and doctrine through systematic man-in-the-loop scenario simulation.

The research approach is to:

a. Fabricate a cutting edge, technically based, man-in-the-loop simulator testbed with:

- modularity for rapid reconfiguration
- helmet mounted and direct view displays
- full combat environment
- full spectrum of visual scene detail
- flexible fidelity aerodynamic models

b. Incorporate a network capability with other advanced simulation systems.

c. Establish three revolving research teams to address:

- training requirements issues
- tactics and doctrine including air-to-air
- testbed for operational capability

The Design Goals are to emulate levels of sophistication from part-task/desk-top level to full-scale/ combat simulation including tactical environment and to evaluate man-in-the-loop performance in a doctrinal context.

System description:

- Fully functioning AH-64 Crewstation:
  - pilot station with fiber optic helmet mounted display
  - copilot/gunner station with rear projection display
  - degradable to part-task/desktop capability with IRIS Graphics Display

- Fixed-base with G-seats
- Cutting edge of technology visual system:
  - Evans and Sutherland ESIG-1000
  - multiple levels of detail
  - allows for visual system fidelity research
- Designed to be networked with multi-level systems
- Modular – separate processors for:
  - flight equations
  - visual scene
  - tactics
  - Elements of each may be changed (e.g., simplified aerodynamics model can be substituted for blade element model)
- Integrated tactical environment management system (ITEMS):
  - provides tactical threat capability
  - includes tactical situation display and database management system
- Blue/red team station for man-in-the-loop tactics interaction
- Long-term performance data collection and online analysis capability

The SCTB is a sophisticated tool for conduct and validation of training system requirements analyses. This simulator represents the state of the art in technology across a number of systems. It permits dissection of complex integrated tasks into skill and decision related components; and ensures that sufficient fidelity is available across training system features to address their effectiveness with respect to specific classes of performance. While the SCTB and devices of this type may be characterized as technology driven, their application in a training system research and development environment is not. These are training development simulators, which will permit definition of training methods driven by and suited to the requirements of the tasks to be trained rather than by the characteristics of the technology at hand.

Use of EEG and MEG in the Development of an Assessment Module for a Driving Simulator

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Abstract

A unique performance assessment module, designed for use with a driving simulator being developed by Concordia University for the Transportation Development Centre (TDC), is described. The module is reported as combining behavioural and electrophysiological (EEG) measurements in order to assess the readiness of brain-damaged and elderly individuals to be re-licensed or to take on-the-road driver training. Also discussed is the application of cognitive retraining programs designed to bring doubtful cases up to readiness level. The use of magnetoencephalography (MEG) during the research and development stage of the module is discussed as a method for estimating the functional brain sources active during information processing while in the simulator environment for the purpose of determining the minimum number of electrodes (and their configuration) to be applied to the patient during assessment in the simulator. Some treatment is given to issues of fidelity, reliability, and validity.

Résumé

Est décrit un module unique en son genre, conçu exprès pour servir dans un simulateur de conduite automobile étudié par l'Université Concordia avec le concours financier du Centre de développement des transports. Associant des mesures béhavioristes et électrophysiologiques (électro-encéphalographie), ce module permet d'évaluer l'aptitude des personnes âgées et de celles ayant subi des lésions cérébrales à reprendre le volant ou à entreprendre le volet routier d'un cours de conduite automobile. Est également décrite l'utilisation de programmes de réhabilitation cognitive destinés à redonner à certains cas marginaux un niveau de réceptivité adéquate. Les travaux de recherche et de développement du module ont fait appel à la magnéto-encéphalographie (MEG) comme moyen permettant de cerner les fonctions cérébrales qui sont actives lors du processus de traitement de l'information par le cerveau humain en milieu de simulation, et ce afin de pouvoir déterminer le nombre minimal d'électrodes à utiliser et leur emplacement préférentiel pour procéder à l'évaluation du sujet placé aux commandes du simulateur. Les aspects réalisme, fiabilité et validité des résultats sont également abordés par les auteurs.

Introduction

As suggested in the paper by Svoboda, Heron, and Weinberg in this Proceedings, there is a significant need for the development of a low-cost driving simulator specifically designed to assess the driving potential of brain-damaged and elderly persons. Many such individuals may be prohibited from driving since, currently, assessing agencies are necessarily cautious and, furthermore, there are no currently available systematic methods of cognitive retraining for driving functions that can be applied to doubtful cases.

The problem mentioned above underlies the development of a microprocessor-based driving simulator by Concordia University for the Transportation Development Centre (TDC). Applied Brain Behaviour Systems Ltd. (ABBS) has subcontracted to Concordia to develop for the simulator an assessment module that classifies patients as: (i) ready to be re-licensed or to take on-the-road driver training, (ii) possibly upgradable to class (i) after cognitive retraining, or (iii) not upgradable to class (i). The work includes design of cognitive retraining programs that are specific to the profile of functional damage as determined by the assessment module. The main purpose of this report is to describe the conceptual framework that forms the basis for using direct measures of brain function to achieve these ends.

Use of EEG

To begin, it will perhaps be useful to explain how direct measures of brain function can be utilized for the measurement and prediction of information processing and of complex motor performance. An evoked (electrical) potential (EP) recorded from the

brain occurs immediately after a stimulus (i.e., some change in the sensory environment such as visual, auditory, or somatosensory input to the brain). An event related potential (ERP) may not be evoked by an input but rather "emitted" or generated by the brain. An ERP not only may be loosely time-locked to an input, but also may occur without an input as, for example, when preparation for an output (motor performance) occurs. ERPs reflect the nature and complexity of the information that must be processed before, during, and after sensory input, and preceding motor input.

Why are direct measures of brain function necessary if external performance is of primary interest? Although performance is a good measure of the existing capability of the physiological system, it may not accurately predict the capacity of that system. There is, in fact a good deal of evidence to the effect that performance and learning can be dissociated – that, under some circumstances, performance does not accurately predict what has been learned. The experience of ABBS with brain-injured patients, and that of others, is that direct measures of brain function measure the capacity of the processing system, even though performance (i.e., external behaviour, or output) may be impaired. If capacity is intact, it is possible that cognitive retraining can make a difference, but unlikely otherwise. Furthermore, if such retraining is made specific to the nature of functional deficits in the information processing system, it is more likely to be successful than if based only on measurements of performance. Thus, a different strategy would be used for a deficit in performance attributable, on the one hand, to functional deficits in short-term memory due to temporal lobe damage and, on the other, to functional deficits in attention due to frontal lobe damage. However it must be emphasized that the systems approach – i.e., the integrated analysis of stimuli, ERPs, and performance – is the most effective.

The CNV and P300

Details of the constellation of ERPs that could be used are precluded in the context of this brief report. However examples of two that are known to index information processing events are the Contingent Negative Variation (CNV) and the positive component of an ERP that occurs at 300 msec after the stimulus presentation (P300). In the assessment module for the simulator under discussion, the CNV and P300 are combined with performance measurements such as reaction time, accuracy, and variability of components of the driving response.

The CNV is a slow electrically negative potential measured from the scalp or cortex. It occurs in the interval between a warning signal and a signal to respond. Its amplitude and character are very sensitive to distraction while its voltage distribution over the scalp is sensitive to the locus of lesions of the underlying brain. P300 is an electrically positive potential, the amplitude of which is inversely proportional to the subjective probability of the occurrence of signal, or stimulus. Much evidence suggests that P300 is a measure of the degree to which memory can be updated on the basis of experience. Like the CNV, P300 is a good measure of the degree to which a stimulus is expected; however the CNV is also influenced by the readiness of the patient to perform a response on the basis of the information content of the ready signal and the signal to respond. Figures 1 and 2 show idealized forms of the CNV and P300 as they might occur for one of the scenarios (the Circle Route) to be used with the simulator being discussed.

The Information Processing Time Line

The processes referred to above can be described as falling within an information processing time line that includes feedback, feed forward, and distributed parallel processing. As Figure 3 illustrates, the time line encompasses the conceptual events that occur during the processing of information as well as the electrical changes that can be measured as indices of that processing.

The information processing time line is useful in determining the nature of the functional deficits that have resulted from head injury or aging. The early components of the EPs originate in the primary stages of input, in the sensory system and in the brain stem. If these components are abnormal, it is unlikely (but not impossible) that training will help. The mid-latency components of the time line originate farther upstream, in the thalamus. All inputs, as well as outputs of the motor system, come through the thalamus. In addition, the thalamus contains systems of basal ganglia that integrate pre-programmed output.

The longer latency components originating from the cortex reflect higher-order processing of input including the comparison of input with existing short-term and long-term memories and the prediction of events on the basis of previous experience. Complex goal-directed performance, requiring monitoring and continuous adjustment of motor systems, is also indexed by such components. If performance deficits are indeed indexed by the longer latency components, there is a better chance

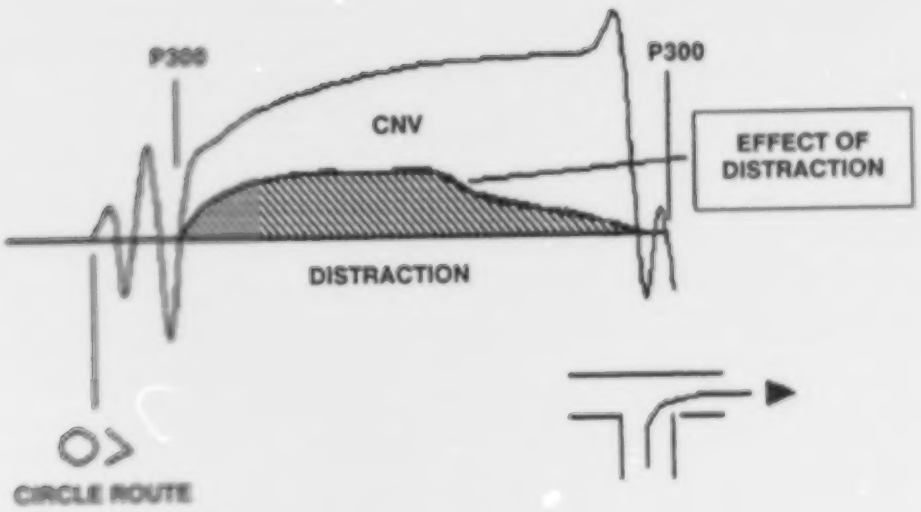

Figure 1: The Effect of Distraction on the CNV

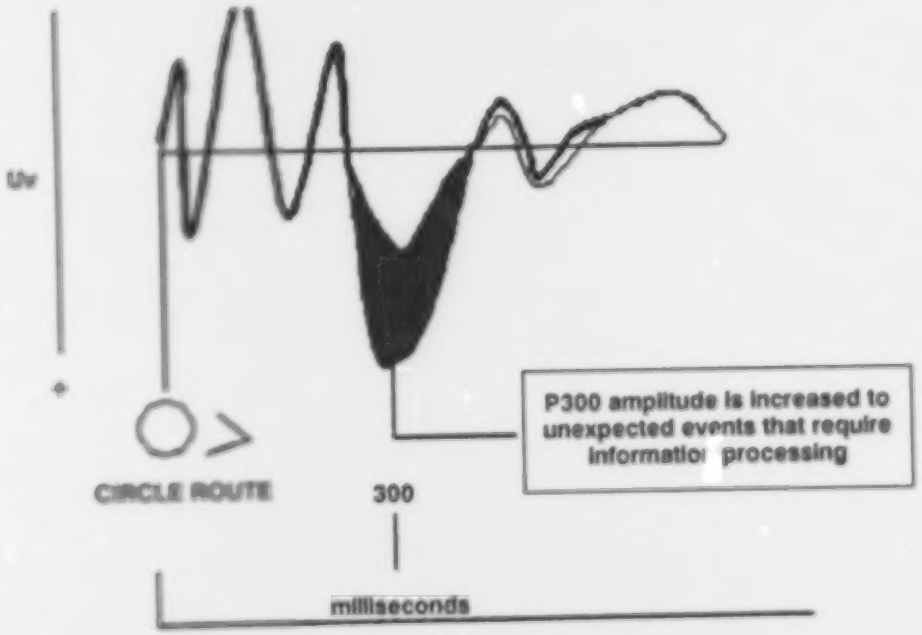

Figure 2: P300 in Response to the Circle Route Sign

that cognitive retraining will make a difference. Furthermore, the retraining can be made specific to the nature of the deficit so indexed. As pointed out earlier, if the performance deficit can be pinpointed to attention deficits resulting from frontal lobe damage, then one specific strategy would be adopted while another would be appropriate for an indication of short-term memory loss due to temporal lobe damage.

The effectiveness of retraining can be monitored by monitoring ERP components in the information processing time line along with external performance measures. The experience of ABBS and others is that, when sustained recovery occurs, there is recovery of the abnormalities in the brain waves. However, under some conditions, performance may improve without improvement in brain waves; in these cases, sustained improvement is less likely.

Use of MEG

If a normal complement of EEG electrodes were to be applied by an operator/instructor using a simulator for assessment or training purposes, collection of ERP data would be impractical because too many electrodes would be required. Therefore some means must be found for greatly reducing the number of electrodes while maintaining the same yield of information from the ERPs. In the project at hand, magnetoencephalography (MEG) is being used during the research and development stage of the testing procedures to obtain a better understanding of sources in the brain that are processing information within the driving environment and, hence, to arrive at the minimum number of EEG electrodes that can be used by the simulator operator, as well their configuration on the testee's scalp.

MEG apparatus consists of a gantry system supporting a large dewar containing superconducting sensors, a noise balancing system, liquid helium which cools the superconducting materials to room temperature, and associated computers for controlling the gantry and processing the data. Figure 4 presents a schematic drawing of the dewar for a 60-channel system now being developed by CTF Systems Inc. and the Brain Behaviour Laboratory of Simon Fraser University, with funding assistance from the Defence and Civil Institute of Environmental Medicine (DCIEM), TDC, and the Department of Supply and Services (DSS).

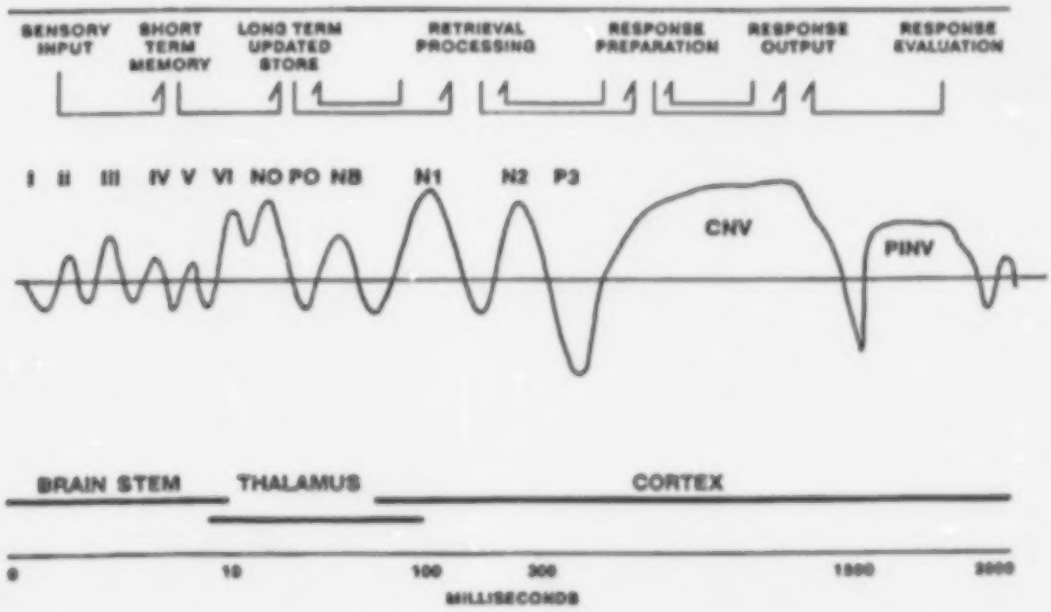

Figure 3: The Information Processing Time Line

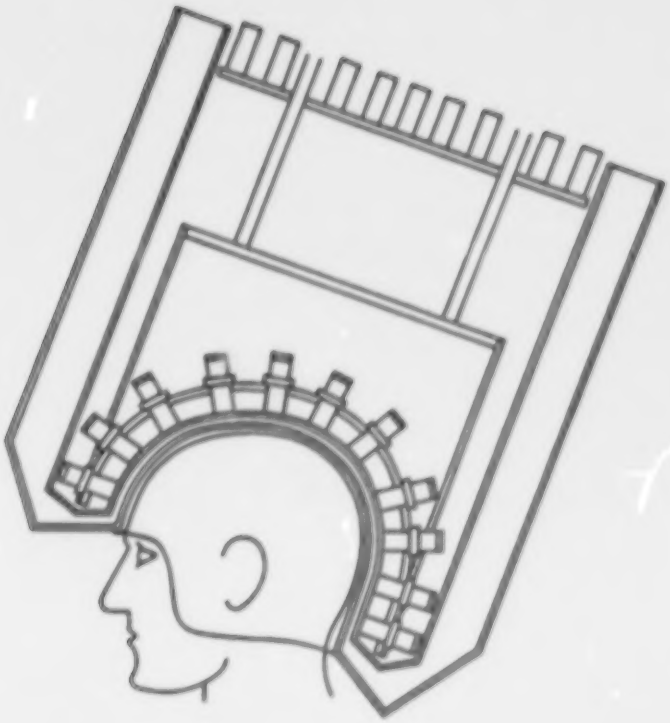

Figure 4: Schematic Drawing of the Dewar for a 60-Channel System

Unlike volume currents, magnetic fields are not smeared as they pass through the brain, skull, and scalp, thus enabling more accurate source localization than is possible with EEG signals. MEG is used in this study to obtain knowledge of which parts of the brain are associated with the electrical fields producing the ERPs (that are indexing events along the information processing time line), and this information is being used to determine the minimum number of electrodes required for the ERP data collection, as well as their precise configuration. As a consequence, the user of the assessment module as a developed product will be required to affix only a small number of electrodes on the testee's scalp, the exact number and configuration being specified precisely by the expert system component of the module in accordance with determinations arrived at in the ABBS laboratory.

Development of Driving Scenarios

A major concern in the development of driving scenarios for the TDC/Concordia/ABBS simulator is that the level of fidelity of the visuals is sufficient for obtaining both behavioural and ERP measurements of brain function that are psychometrically reliable and valid indicators of on-the-road driving readiness of brain-damaged and elderly individuals. For this reason, it is considered essential that the ERPs result from the processing of information contained in the scenarios while the individual is "driving" the simulator.

A starting point -- one intended as a first step toward indicating the level of fidelity required and ensuring validity -- was to carry out intensive consultation with occupational therapists involved in driving programs for the target populations. From the domain of driving behaviours developed on the basis of these sessions, it was possible to infer in a broad sense the type of information processing involved as well as the difficulties of the brain-damaged and elderly with such processing.

After analysis of the items mentioned above, it was concluded that a suitable level of fidelity would require that information having to be processed

as distraction be superimposed on scenes incorporating basic perceptual principles of perspective, colour, and contrast. The distracting stimuli to be used include vehicles that follow, precede, and come to a stop in front of the driver, pedestrians that are strategically placed with respect to the intersections, and traffic lights intentionally designed to maximize the diverting effect. Accordingly, a demonstration scenario was designed that includes the tachistoscopic presentation of information that would result in the relevant ERPs. This scenario, called the Circle Route, is one of three routes on a map consisting of 70 blocks, each containing an urban intersection (see Figure 5 for a bird's eye view). Every block in the Circle Route has an information sign on the driver's side of the road, indicating the route to follow (by either a circle, square, or diamond) and the direction to take for the route (by an arrow).

Unlike signs available in the real world, the Circle Route signs are not placed so as to be visible at all times as the driver approaches the intersection. The sign appears as a blank on the sign post at time t_0 (time 0) about 92 m before the intersection (assuming the subject is travelling at the posted speed of 50 km/h). At time t_1, 2.4 seconds after t_0, the route symbol appears. At time t_2, 2.4 seconds after t_1, the direction indicator is added to the route symbol. At time t_3, 0.4 seconds after t_2, the driver passes the sign and either proceeds forward or makes the appropriate turn, depending on the route symbol and direction indicator. If the driver is travelling at approximately 50 km/h the driver passes the sign at 20 m from the intersection (see Figure 6).

The Circle Route consists of 16 turns, 8 left and 8 right, this resulting in a combination of route symbols, direction indicators, and traffic control lights such that there are 16 possible correct driving responses. At the posted speed limit of 50 km/h, the total time to complete the Circle Route is approximately 17 min, including stops for traffic control signals. If the driver deviates from this route, the system will be stopped, the driver relocated to some point after the intersection of the previous block, and the system restarted. A TTL pulse will be available at t_0 (see Figure 6) for the purpose of triggering an ERP signal averaging system. Electrical signals of the brain will be recorded beginning at a fixed interval following t_0 for an interval that includes the time of the turning response. These signals will be averaged to produce an ERP that includes both P300 and a CNV.

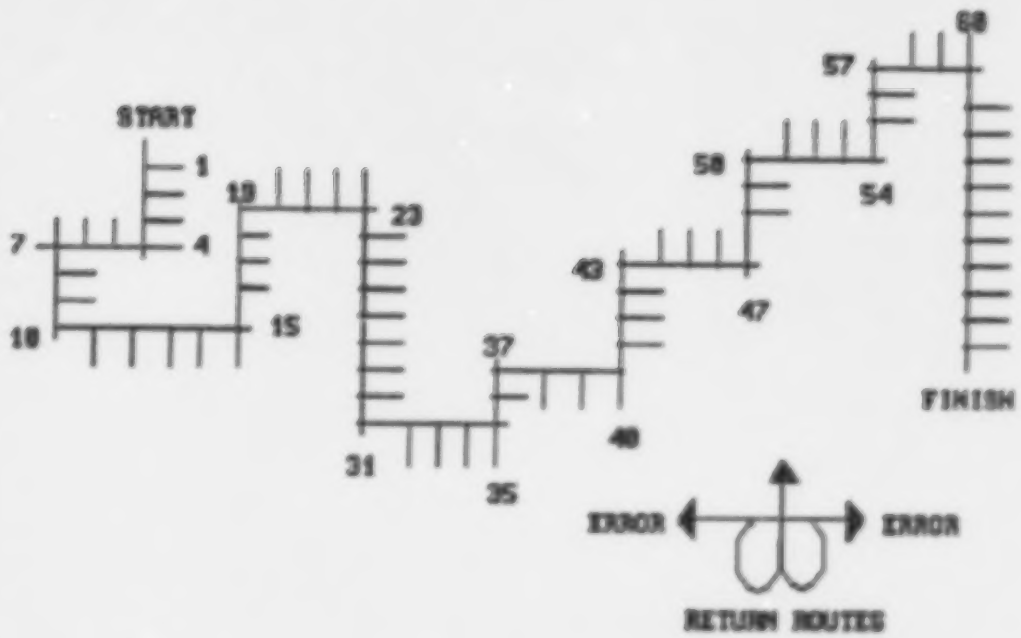

Figure 5: The Bird's-Eye View of the Circle Route

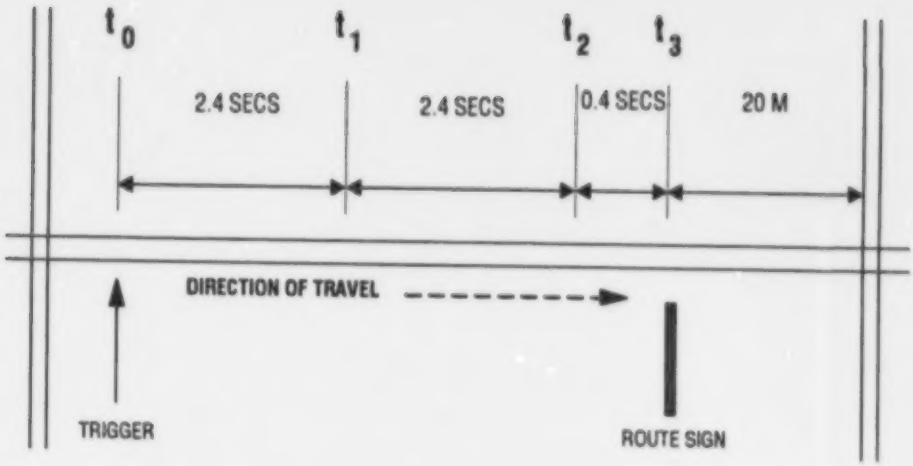

Figure 6:
Position of Car in Relation to the Appearance of the Route Sign Components

An example of a typical scene in the Circle Route is shown in Figure 7. In this scene, the sign signals the driver to go straight ahead if he or she were to follow an incorrect route (as indicated by the square symbol.) The driver encounters two types of distraction on the Circle Route, namely, vehicular traffic and a pedestrian crossing a street. The sequence of distracting events is semi-random.

Reliability and Validity

Reliability of all measures, electrophysiological and behavioural, will be established by the test-retest method. Validity is a more difficult issue to address. Construct validity inheres in the test items inasmuch as they were gleaned from occupational therapists familiar with the driving behaviour of brain-damaged trainees. However field validity will also need to be demonstrated. In this respect it can be said, first, that occupational therapists do not recommend brain-damaged patients for relicensing, or take them onto the road for driver training, unless they have a very high degree of certainty that safety will not be violated. It follows that the validity of the tests on which their judgments are based is high to the extent that patients that do go on the road drive safely. The expectation for ERP measurements and cognitive retraining is that, together, they will increase judgment certainty and, hence, free up doubtful cases for on-the-road activity. Accordingly, the validity of these measurements will similarly be demonstrated by safe driving records of the freed-up patients. An attempt to obtain relevant data is being considered. Also being contemplated is a follow-up study in which correlating simulator and on-the-road test results will represent another approach to field validity.

Conclusion

The account above describes a unique approach to the simulator assessment of brain-damaged and elderly individuals for on-the-road driving being developed with the expectation of increasing precision in measuring perceptual/cognitive deficits and, thereby, of opening up driving opportunities for these populations. Although it must be remembered that the work is so far exploratory, early results augur well for an efficient assessment module that complements and enhances the overall simulator system. If so, it can be said with confidence now that the techniques will be applicable in any context where precision in the measurement of human performance and economy in decision-making are important.

Figure 7: A Typical Scene in the Circle Route

Acknowledgments

Funding for the simulator project contracted to Concordia University is provided by TDC under the Elderly and Disabled Program, the Transport Canada Disabled Persons Program, and the Department of Supply and Services. The initial development phase was carried out by Concordia as a subcontractor to CAE Electronics Ltd. The authors are grateful for contributions to the project by R. Nishizaki (TDC), the Constance Lethbridge and Ottawa Rehabilitation Centres, and the staff in the Concordia and Applied Brain Behaviour System laboratories.

Roles of Simulators in the Railway Industry: Human Factors — Trainees-Trainers

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Abstract

This paper presents a number of observations on simulator training and the human factors associated with this type of training. The background on the need and use of simulators in the railway industry is discussed with emphasis on the value of fidelity in simulation. Performance evaluation, the transfer of training, the role of the Instructor as an integral part of simulator training, the interaction between the instructor and the trainee and the necessity for further improvements and upgrading in simulators and performance evaluation are reviewed.

Résumé

L'auteur présente diverses observations concernant le simulateur comme outil d'apprentissage ainsi que les facteurs humains qui lui sont reliés. Il fait la genèse du simulateur en milieu ferroviaire en mettant l'accent sur l'importance du réalisme du rendu. Les questions abordées sont l'évaluation des performances, le transfert des connaissances, le rôle de l'instructeur comme partie intégrante du processus d'apprentissage à l'aide du simulateur, l'interaction stagiaire-instructeur, la nécessité de créer des simulateurs plus puissants et plus performants et de perfectionner les techniques d'évaluation des performances.

Introduction

It gives me a great deal of pleasure to be asked to give you a presentation on the use of simulators at our CN Transportation Training Centre, Gimli, Manitoba.

Canadian National Railway's Transportation Traning Centre has been using simulators since the early 1970s. We have recently performed a multi-million dollar upgrade of our simulators which is a testament to the effectiveness of simulator training.

Interest in locomotive simulators has increased dramatically in the last few years as simulators can offer reduced learning time, improved safety, reduced fuel consumption and efficient and effective refresher training. The push for formality in licencing new engineers and in recertification adds further impetus.

This presentation has been prepared in order to acquaint you with CN's approach to the simulator age with both student and qualified locomotive engineers, as well as the human factors associated with the training and assessment.

Let me begin with a short background on the reason simulators are in use at CN's Trainig Centre. During the early 1970s, there was a need for more locomotive engineers because the traditional sources for such personnel no longer existed on CN. It also became apparent that every effort should be made to provide a uniform standard of training for locomotive operating personnel and to seek improved methods of training. In 1972, CN started an engine service training school where railway personnel with no previous train handling experience could be taught the basics of this skill.

The only special equipment that was available at that time was a mock up of a locomotive air brake rack. This was very primitive training equipment and it was quickly recognized; something more was required.

An early investigation of availability of simulator equipment showed that suppliers did not have any direct knowledge of railroad technology and were found lacking in the understanding of train and railway vehicle dynamics.

It became apparent that we would have to determine what the training needs were and to design and develop the required simulator system in house.

In 1973, the first of three simulator systems was installed at Gimli. Because our first locomotive mock up in the school was named Oscar I, this simulator system gained the name of Oscar II.

Oscar II has a completely operational locomotive control stand, mounted within an enclosure which was scaled to be a replica of the right half of a 3000 horse power locomotive cab. A computer was used to monitor cab controls, compute train response, and control student displays. This system

initially utilized a 16 mm motion picture visual system which projected on a rear projection screen. It has since been upgraded to a 35 mm projection system.

After the installation of Oscar II, a long-term plan was developed so that additional components could be added on a stage-by-stage basis. Therefore, the simulator could grow and changes evolved with each addition; the training capabilities could also be evaluated, and different aspects of need examined.

The experience gained during the operation of the basic simulator system served as a guide to the development of the larger more complex simulators. In particular, the pattern of simulator usage became more clearly defined and the development of lesson plans necessary for effective training took place.

Installation of the final two simulators occurred in two stages. Oscar III in 1975 and Oscar IV in 1978.

Oscars III and IV are actual MLW and GM locomotive cabs with visuals, sound, and a motion system which gives the sensation of actually operating a train over a piece of track.

However, we can't just look at the simulator in isolation; we must examine the setting in which it is used, the total environment, the type of student (i.e., student locomotive engineers versus the qualified locomotive engineers), course length and content. We must consider the intent of the simulation.

At CN, our major experience is with student trainees, which has ramifications on the organization of the Training Centre, the hardware and software required, the course layout and any observations of human factors.

CN's use of simulators is perhaps a corporate goal to ensure that locomotive engineers are trained in the proper handling of a train under most circumstances. Our training is generic training, not specific to a territory or train type, which creates a solid experience base for the trainee to build upon.

Human Factors – Trainees

From this background, we can make some observations of the human factors, but many factors are interwoven, for example, course and mission design, physical and psychological impacts, technical and usually economic effects. They are not generally separate in their impact but influence several things concurrently.

Our intent of simulation is to increase the complexity of the training missions by varying both techniques and situations. We have nine missions of two runs each. Initially, trainees cannot cope with all the stimuli needed to operate a train, they are overloaded, hence, lower fidelity simulations are used. These early runs have heavy instructor coaching and no film. This then progresses to visual runs on OSCARs II, III and IV, using different scenarios and scripts, urban to mountain, slow speed, high speed, medium grades to high grades, as well as varied trains (light, medium or heavy). There is debriefing after each run, using the computer printout to show the variances.

Research on the need for fidelity in simulations confirms that we have instinctively used the right approach at Gimli by increasing both the complexity and fidelity of the simulations as the trainees become more familiar with the simulator and gain experience. Without experience, the trainee is unable to cope with a full real life simulation.

Initially, students are awed and apprehensive of the simulators, sweaty palms and butterflies in the stomach are common in early missions. The student becomes more relaxed as time passes.

We have concluded that simulation realism and complexity should increase, with experience, to prevent overload and maximize learning of skills. For refresher training of qualified personnel, we suspect fidelity is more important as a stimuli for this group.

Problems in Use of Simulators for Trainees

There are both economic and inherent technical constraints to using simulators. Some limit simulation capabilities while others restrict fidelity.

Motion System

The motion system was designed to simulate the motions experienced in a locomotive and include both the general ride characteristics (e.g., Roll, Lateral, Vertical) and longitudinal forces (slack action or run-ins). These motions of the locomotive used during filming are not synchronized with those generated by the simulator. While you could probably synchronize the visual and simulator motion, it would be both difficult and expensive. We have experienced the odd case of motion sickness and we suspect the students' queasy stomachs are more than just nervousness and feel it is linked to this lack of synchronization.

Sound System

A synthesizer is used to generate the sound patterns of locomotive throttle positions one to eight, bell and whistle. A computer controlled transducer is

used to simulate the exhaust of brake pipe air during brake pipe reductions. This exhaust varies with train length and leakage, and thus adds to the realism of simulation. Realistic sounds are an important part of learning, and in many cases, cues for action.

Visual System

The visual system recreates the forward view as seen ahead of the locomotive. It adds realism and often provides situations requiring some kind of response. The fidelity of this system is very important to convince the student that the training is truly representative of actual performance.

Speed realism generally depends on how close your simulated speed is to the original filming speed. Therefore, both the mission's design and how the student handles the train reflect on speed realism. There is nothing that can beat the versatility and capability of the human eye. Visual limitations have required a large amount of design effort to improve this simulation element. Laws of optics and the visual recording process affect the degree of visual realism whether on film or video. It is the process that constrains, not necessarily the medium.

Any of our simulators meet the visual needs of trainees and while there are constraints and limitations, they are workable.

Performance Assessment

For any performance, there must be some method of evaluating the results. Computer generated end of run reports give us a summary of the mission just completed by the student. They show us a number of critical factors in assessing the performance, such as speed, brake pipe pressures, in-train forces generated, fuel consumption, total mileage operated, type of braking (air or dynamic) and all actions of the student that can be computer recorded.

The instructor, through observation of the student and on a check form, assesses other factors such as student's observation of the gauges, use of bells and horns, use of radio and any information that cannot be computer generated. The students are debriefed on all aspects of their simulator run covering each phase of the assessment and how well they did compared to our standards. This information is compiled and a pass-fail mark is applied. The feedback is an extremely important part of the student's learning process. This portion of the course corrects inappropriate action and hopefully prevents unfortunate errors in the future.

The one-to-one instructor-student relationship during simulation and debriefing allows the instructor to recognize human factors that could be affecting the trainee's performance whether good or bad.

The attitude of the trainee towards the goals of the course are recognized very quickly. There are those students who want to learn all there is to know and some who are willing to just get by.

The stress created by the possibility of failure, combined with being away from their families for five weeks, is evident. Self confidence or lack of it, planning skills and reaction time are all recognizable and must be dealt with.

At the end of the course, final assessments are forwarded to their home Supervisors. This will ensure that the proper attention is directed towards correcting any weaknesses we observed.

A major problem we have encountered is that all students do not progress at the same rate. Due to the structured nature of the training course, there is little room left for extra assistance. Slower students are either disqualified or complete the course with a lower skill level. This will usually result in longer (costly) training in field trips.

Transfer of Training

Prior to using procedural simulators, the training course was nine weeks long with up to six months of road training to become a qualified locomotive engineer. The course is now five weeks long with road training substantially reduced.

We have found that 20 hours on a simulator results in a reduction of approximately 40 road trips to qualify and 30 hours simulation reduces qualification by approximately 60 road trips. There is also evidence that simulator training reduces fuel consumption considerably, one of our major operating expenses. Therefore, the use of simulators is cost effective.

From the trainees' viewpoint, they will be less apprehensive when operating a real train. They will qualify sooner and therefore have the opportunity to earn a larger income in a shorter time frame.

Safety is a prime concern and much has been written attributing the reductions in accidents to simulator training. There is little doubt that train accidents, chargeable to engineers, have decreased since the introduction of the simulator program. One of the reasons is a better trained employee, in which the simulators are the key component.

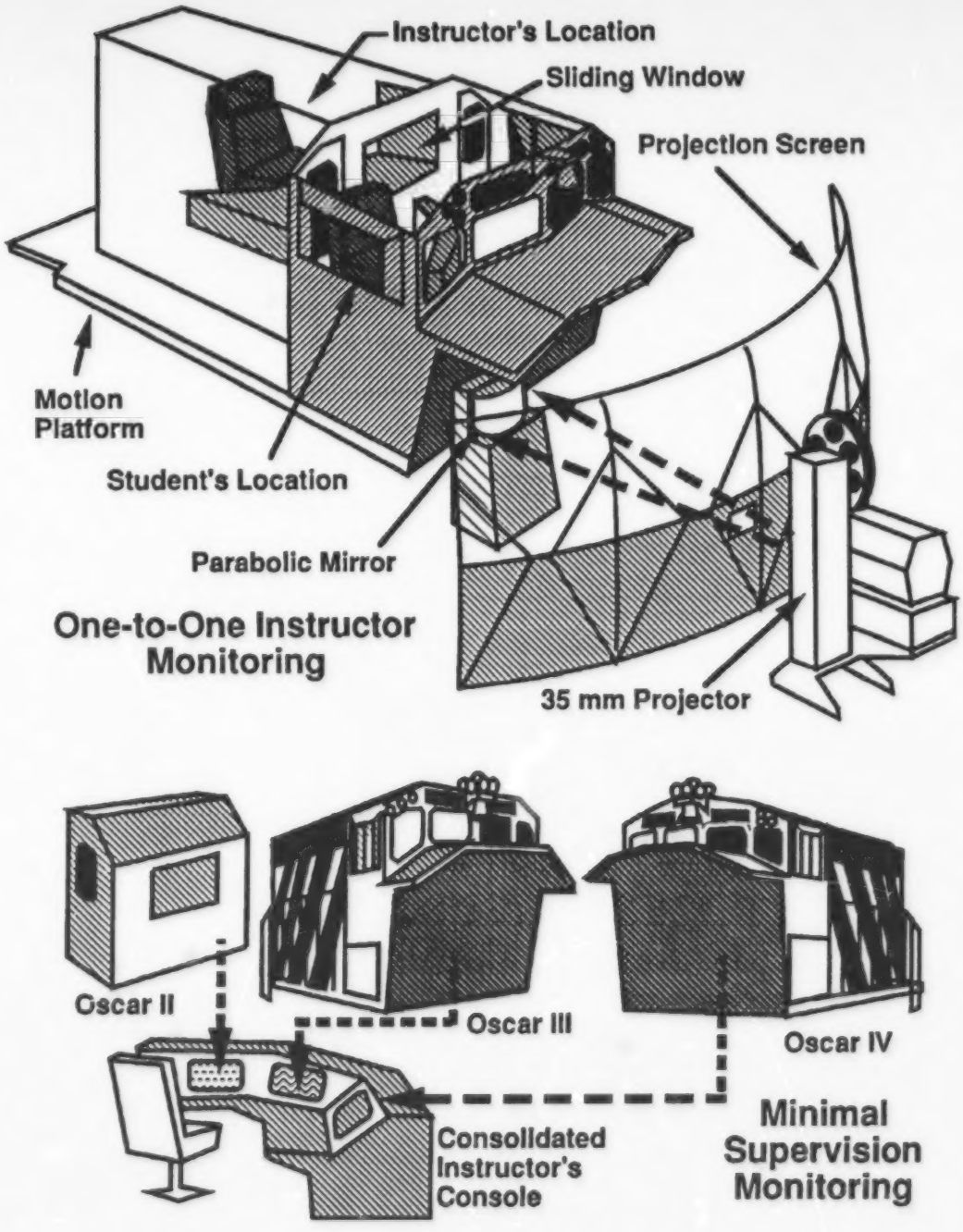

Figure 1: One-to-One Instructor Monitoring vs Minimal Supervision Monitoring

Instructor's Role

The instructor's role is to control and monitor the simulation exercise. The instructor is located behind the student in an area immediately behind the cab bulkhead on Oscars III and IV. A window glass can be opened to permit direct communication between the instructor and the student. An audio communication channel provides a simulation of the locomotive radio and is used both as an instruction tool and to simulate radio communication with others.

The main advantages of these arrangements are the ease of communication and the assessment of the student's performance. It allows a quick, efficient way of giving guidance and correcting faults immediately.

Human Factors Affecting Instructors

All that has been discussed has effects on the instructors. They must recognize these human factors and must learn to cope with them.

Discretion, judgement and tact are important elements for instructors.

It is difficult at times to be objective and unbiased when giving the assessment, to recognize the trainees' past experiences and to recognize the interpersonal relationship that has developed between the instructor and the trainee.

Because the instructor is located on the motion platform and is subjected to these forces usually for five hours a day, combined with the boredom that can develop riding the simulator, we rotate instructors between the simulator, classroom and support functions. However, even this does not stop burnout and malaise, depending on the individual instructor's basic temperament.

Therefore, we generally try for a three-year term at the Training Centre, with the instructors being transferred back to their home regions as line officers after this tenure.

Conclusion

In order to reduce staff costs, and handle a larger volume of trainees, we are in the midst of upgrading our monitoring process by installing a consolidated console where an instructor can monitor OSCARs II, III and IV at one time from a separate room.

We will then have the option of selecting a one-to-one student-instructor relationship for closely monitored performance evaluation or a configuration where more experienced students can perform practice exercices or be evaluated with minimal supervision (see Figure 1).

Added to this will be a computer generated proficiency test. The test marking will take into account the experience of the student. The computer will produce a fail-pass percentage according to parameters we set. This process will be an evaluation with minimal instructor bias.

As mentioned at the outset, the subject is not straightforward but interwoven with many factors such as the target population, course goals, simulator and course design, and economics.

The use of the simulator in showing the cause and effect of one's actions, whether technical or human factor related, is an invaluable training tool.

We are convinced that simulator trained students are better qualified to cope with the problems they will encounter in the field, and to give CN a better overall operation.

Première étape du contrôle de performance dans la navigation maritime en simulation

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Préambule

Je voudrais prendre cette opportunité pour montrer comment nous essayons de normaliser l'évaluation des candidats basée sur leur performance durant un exercice fait dans un simulateur de radar. Cet exposé est divisé comme suit:

1. Historique
2. Plan pour se conformer au NFCOQ
3. Établissement des normes pour un examen national
4. Méthodologie pour achever la normalisation
5. Futures étapes du contrôle de performance

Ci-joint, vous trouverez les directives et les guides développés afin d'atteindre notre objectif.

Historique

Pendant les dernières vingt années, les instituts maritimes canadiens de formation ont utilisé des simulateurs pour former leu officiers de pont. En 1977, la section Sécurité des navires de la Garde côtière canadienne établissait deux cours employant ces simulateurs de radar marine: le premier, appelé cours de navigation électronique simulée, Niveau I (NES I), était destiné à donner des connaissances et pratiques requises pour être un compétent chef de quart; le deuxième, Cours de navigation électronique simulée, Niveau II (NES II) était pour les officiers aspirant à commander un navire.

Les deux cours concentrent leur enseignement dans l'utilisation de l'équipement électronique de navigation pour diriger avec sécurité un navire.

Entre-temps, la Convention sur les normes de formation et de certification des officiers de quart (NFCOQ) était tenue par OMI en 1978. Cette Convention devint effective au Canada seulement le 6 février 1988.

Plan pour se conformer aux NFCOQ

De 1984 à 1988, la Garde côtière canadienne devait réviser ses normes de qualifications pour tout le personnel, pont, machine et radio afin de se conformer à la Convention.

Cela comprenait des amendements pour les cours de NES-I et NES-II. Avec la coopération de tous les instituts de formation maritime du Canada, ce travail a été accompli avec succès. Les objectifs de performance et de formation pour chaque cours ont été rédigés, et les normes minimales nationales que les candidats devaient atteindre pour réussir ont été établies[1].

Au mois de septembre 1989, les cours révisés de NES-I et NES-II étaient offerts. Un examinateur de la section de la Sécurité des navires de la Garde côtière canadienne examine chaque candidat pour voir si il/elle a atteint les normes minimales. Ces examens sont appelés SIM-I et SIM-II.

Normes pour un examen national

Au mois de mars 1990, l'Institut de formation de Transports Canada faisait l'objet d'une demande d'organiser et de diriger un atelier NES pour examinateurs par la Direction de la sécurité des navires de la Garde côtière canadienne. Le but de cet atelier était de développer des normes pour un examen et des guides de notes pour évaluer la performance des étudiants au moment de l'examen au simulateur.

Les guides pour donner des notes n'étaient pas agréés sans de considérables discussions. Les décisions n'étaient pas atteintes de façon unanime. Cependant les participants étaient d'accord que ces guides représentaient le meilleur effort dans un premier temps vers une normalisation de noter les étudiants sur une base nationale.

[1] *TP 4958, Cours de navigation électronique simulée.*

Même avec les normes de performance et objectifs de formation à leur disposition, les participants de l'atelier ont eu de la difficulté avec les points suivants :

1. la définition, pour une tâche donnée, d'une performance acceptable et satisfaisante;
2. l'importance relative d'une tâche donnée en relation avec la performance globale de l'étudiant (à savoir, diriger avec sécurité un navire d'un point A au point B);
3. la décision qu'une tâche soit évaluée subjectivement ou objectivement;
4. la détermination d'une méthodologie à être utilisée lorsqu'on examine une tâche donnée.

Un nombre d'autres facteurs ont été combinés pour produire un guide national normalisé de noter les élèves. Ces facteurs sont les suivants :

a) Disparités des équipements de simulateur -- au niveau des zones disponibles pour exercices et aussi au niveau des capacités de divers simulateurs pour exécuter certaines tâches.

b) Manque de temps -- les demandes opérationnelles exigent qu'un minimum de huit étudiants soient examinés en une journée quand on utilise un simulateur à quatre navires.

c) La demande que les exercices soient réalistes -- l'interaction entre navires, sous la commande des candidats, produit un meilleur effet mais crée aussi un exercice qui est à la fois difficile pour l'examinateur de préparer et difficile à analyser.

d) Subjectivité du matériel -- le fait que nous examinons les techniques plutôt que les résultats.

e) Un examinateur aurait à noter quatre candidats pendant un exercice.

Méthodologie

Bien qu'il soit reconnu que le but de l'examen SIM n'est pas d'évaluer la performance du candidat dans le cours de NES, le contenu du programme de chaque cours NES indique la connaissance qu'un candidat doit posséder lors de l'examen correspondant SIM.

Avec ceci présent à l'esprit, tous les sujets d'enseignement et le temps consacré pour chaque sujet dans chaque programme de NES étaient analysés. Quand combiné avec un facteur d'équilibre représentant leur importance relative et la possibilité d'être effectivement examinée, on obtient pour chaque sujet un pourcentage du total des notes. Là où un sujet pourrait être objectivement évalué, des critères d'erreurs majeure et mineure étaient établis. L'évaluation subjective était développée pour le reste des sujets. Des exercices d'essai étaient alors évalués selon ces critères pour vérifier la consistance.

Les résultats préliminaires de ces exercices d'essai montraient que le guide et les formules utilisées étaient la meilleure méthode pour arriver à une forme consistante dans l'évaluation d'un candidat. Pendant l'essai, l'évaluation variait dans une limite de plus ou moins 5% quand deux ou plusieurs examinateurs évaluaient le même candidat.

Formation des examinateurs

Comme nous sommes dans la première étape du contrôle de la performance, la formation des examinateurs dans la conduite de tel examen est vitale. La Direction de la sécurité des navires de la Garde côtière canadienne a organisé des ateliers, presque sur une base annuelle, pour donner aux examinateurs des pratiques et connaissances pour pouvoir faire ces examens de façon adéquate. Ces ateliers étaient complétés par des séminaires NES bi-annuels, où les examinateurs et instructeurs de divers instituts de formation maritime révisent la méthodologie des programmes et les examens correspondant à ces cours.

Ces ateliers et séminaires sont essentiels non seulement pour permettre aux instructeurs et examinateurs d'être au courant des derniers changements technologiques mais aussi pour rehausser notre système de contrôle de performance au Canada.

Conduite des examens de SIM-I et SIM-II

Au cours des examens passés dans le simulateur, il pourrait être surprenant de savoir que non seulement l'étudiant est sous pression mais aussi l'examinateur.

Lors de notre dernier atelier de mai 1990, nous avons demandé aux examinateurs quels étaient les facteurs qui leur causent le plus de tension quand ils sont en train de faire un examen. Je voudrais vous communiquer ici leurs commentaires.

- La plupart des examinateurs ne sont pas familiers avec la manipulation des simulateurs et de leurs caractéristiques opérationnelles. Ils comptent totalement sur l'instructeur pour diriger l'exercice.

- Les examinateurs ne sont pas toujours totalement familiers avec les scénarios de l'exercice et le trafic attendu pour un exercice donné. Ceci est un facteur très important dans la conduite d'un examen Stité-II. Nous essayons de minimiser l'effet du manque de familiarisation avec l'exercice en demandant aux instituts nautiques de soumettre des exercices avec des scénarios explicatifs.

- Le nombre de candidats à évaluer en même temps dans un court intervalle de temps. Parfois quatre candidats doivent être évalués dans une période de trois heures.

En ce qui concerne les candidats, le niveau de tension varie d'un sujet à l'autre. Le guide de marquage va certainement réduire la pression sur eux : ils sauront comment ils seront évalués, combien de points ils perdront pour une erreur donnée. Le guide de marquage est un outil pour le candidat qui veut savoir ce qu'on attend de lui pendant l'examen. En établissant les guides, nous avons essayé de minimiser la subjectivité de l'examen et rendre le processus des examens plus uniforme à travers le Canada quel que soit l'endroit où il a eu lieu.

Les futures étapes du contrôle de performance

Nous avons seulement commencé le système de contrôle de performance dans la simulation marine. Nos efforts futurs dans le but d'atteindre un standard national dans les examens utilisant un simulateur de marine devraient se concentrer sur les points suivants :

1. L'ensemble des normes minimales contenues dans le TP 4958 devrait être révisé sur une base régulière et raffiné.
2. Nous devrions mettre une plus grande insistance sur les facilités disponibles pour le contrôle de performance lors de l'acquisition de futurs simulateurs.
3. La formation des examinateurs dans le contrôle de performance lorsqu'on emploie un simulateur de marine doit être augmentée. Nous avons commencé ce processus et nous souhaitons que des ressources continueront d'être disponibles pour amener le programme à son but.

Avec la coopération de toutes les parties intéressées, j'ai le sentiment qu'une norme nationale pour des examens utilisant des simulateurs peut être atteinte dans un avenir proche pour soutenir nos objectifs principaux.

« En formation pour votre sécurité

et

contribuer à une sûre, efficace et économique conduite des activités de marine. »

ANNEXE

Guide pour noter l'examen de SIM-I

Les cas suivants entraîneront automatiquement un échec :

1. Collision (échos des navires se fondant sur l'écran PPI)
2. Échouement
3. Le candidat n'a pas réussi à faire un pointage (le triangle M.O.T.)
4. Le candidat quitte la salle d'examen sans permission.

Pointage (30 points) Évaluation objective

10 Détermination des données (route, vitesse, point d'approche minimale et temps d'approche minimale).

15 Manoeuvre d'évitage.

5 Reprise de la route initiale employant le pointage.

Radio (5 points) Évaluation subjective

Instruments de navigation (15 points)

Erreur majeure

10 points :

échec dans le réglage correct des instruments.

Erreur mineure

5 points :

échec dans les ajustements mineurs des instruments ou dans la reconnaissance des défauts du système.

Cartographie (15 points)

Une erreur majeure entraînera une déduction de 10 points.

10 points :

échec dans la reconnaissance et l'utilisation des échos radar de terre.

10 points :

erreur non aperçue dans la détermination de position.

10 points :

n'a pas réussi à changer de cap pour suivre une route prédéterminée.

Une erreur mineure entraînera une déduction de 5 points.

5 points :

n'a pas réussi à déterminer la position du navire à intervalle régulier.

5 points :

n'a pas réussi à suivre une route prédéterminée.

Tenue du journal (10 points)
Évaluation subjective

Règles de barre et de route (20 points)
Évaluation subjective

Une erreur majeure entraînera une déduction de 15 points.

15 points :

non-observation des règles de barre et de route.

Cartes et publications (5 points)

La connaissance du candidat sera évaluée au cours de la session de compte rendu pendant laquelle l'examinateur le questionnera à ce sujet.

PERFORMANCE ASSESSMENT

S.I.M. 1

Name :.....

CDN #:.....

ITEM	MAJOR	MINOR	COMMENTS	RESULTS OBTAINED
Plotting (30) (10DA:15A/C SR)				
Navigation (15) Instruments (15,10,5)				
Rules of the Road (30) 10 Assessment 10 Action				
Chartwork (15) (10,5)				

Subjective Factors	Ratings (Tick one Only for Each Factor)				
	100%	**75%**	**50%**	**25%**	**RESULTS OLBTAINED**
Radio Communications 5	Follow procedures Timely Precise	Follow procedures Timely Few Errors	Errors in procedures Timely Rough	Frequently incorrect Untimely Rough	
Record keeping 10	Complete Accurate Easy to follow	Incomplete Accurate Easy to follow	Incomplete Errors Inaccurate	Disorganized Incomplete	
Charts & Publications 5	Answers all questions correctly	Needed help to answer some questions	Could Not answer some questions	Misses most questions	
Chartwork 15	Accurate Symbols used Allows for current Neatness	Few errors Symbols used generally Allows for current Neat.	Errors Symbols not used Allows for current Neat	Frequent errors No symbols Current not corrected Untidy	

Comments :

Signature :.....

Guide pour noter l'examen de SIM-II

Les cas suivants entraîneront un échec immédiat :

1. Échouage
2. Collision
3. Abandon de l'exercice avant la fin
4. Omission de produire un plan de voyage

Préparation (27 points)

Préparation de voyage : 20 points.

Mise en marche et réglage des instruments : 7 points.

Erreurs majeures

15 points :

tracer une route telle que si elle est suivie elle conduira le navire à un échouage.

15 points :

tracer une route en contravention de la règle 10.

10 points :

tracer une route trop près d'un danger isolé.

Erreurs mineures

3 points :

omission de noter des informations significatives sur les cartes ou dans le journal.

Lors de l'examen du plan de voyage, l'examinateur s'assurera que les informations suivantes sont disponibles sur les cartes et le cahier de notes de l'officier de navigation.

Cartographie

1. Choisir les cartes et tracer les routes pour un passage d'environ 20 milles nautiques.
2. Indiquer les points de changement de route et les points où la barre devra être appliquée.
3. Marquer toutes les zones de danger proches des routes prévues.
4. Marquer les points d'appel et la distance au prochain point.
5. Indiquer les points où une manoeuvre de la machine est requise.
6. Fournir des informations concernant l'utilisation des lignes parallèles sur la carte ou les coordonnées concernant les éléments qui servent à construire une carte électronique sur l'APRA.
7. Identifier sur la carte les points de référence choisis pour les lignes parallèles.

Cahier de notes du navigateur

Les informations (7) ci-dessus devraient être inscrites dans un cahier de notes, ou sur une feuille volante, en bon ordre et lisibles ensemble avec les suivantes :

8. Les heures de haute mer / basse mer et informations sur les courants des marées.
9. Information sur le pilotage si applicable.
10. Distance totale et durée de passage à la vitesse proposée.

Exécution (45 points)

1. Cartographie et pilotage : 15 points.
   - indiquer les positions à intervalles réguliers,
   - appliquer les corrections de dérive due au courant/vent si nécessaire,
   - rectifier la route si dérivé en dehors de la route initiale,
   - utiliser les lignes parallèles pour accomplir les opérations ci-dessus et prendre le mouillage ou embarquer le pilote, etc.
2. Évaluation du trafic et manoeuvre anticollision : 15 points.
   - évaluer les cibles (par l'utilisation du pointage relatif ou de l'APRA),
   - marquer les décisions et décisions prises en accord avec les règles de barre et de route.
3. Conditions spécifiques de l'exercice : 10 points.

   À savoir :
   - système de séparation du trafic,
   - gestion du trafic maritime,
   - réglementations portuaires,
   - etc.
4. Utilisation de la radio : 5 points.

PERFORMANCE ASSESSMENT

S.I.M. 2

Name:.....

CDN #:.....

Execution	Subjective Rating				RESULTS OBTAINED
	100%	75%	50%	25%	
Chartwork and Pilotage 15	Efficient use of P.I. Keep to plan fix positions	Good use of P.I. Slow to return to plan Fix Positions	Use occasionally P.I.Slow to return to plan Fair position fixing	No use of P.I. Do not follow plan Poor position fixing	
Traffic Assesment and Collision Avoidance 15	Assess Traffic accurately Timelyactions. All factors considered Follows R.O.R.	Assess Traffic accurately Actions usually timely and all factors conside-red. Follows R.O.R.	Fair assesment of Traffic Slow to take action Most factors considered Fair interpretation of R.O.R.	Poor Assesment Misses important factors to assess and actions untimely Poor interpretation of R.O.R.	
Use of Radio 5	Efficient use of Radio for anticollision Follows procedures Correct at all times	Good use of Radio for anticollision Does not follow procedures at all times Frequent errors	Use of radio for anticollision not efficient Follows procedures and timely most of the time Makes errors at times	Poor use of Radio for anticollision Does not follow procedures at all times Frequent errors	
Overall Comprehension 14	Can Justify All	Can Justify Most	Can justify Few	Can justify Some	

Comments

Signature:.....

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